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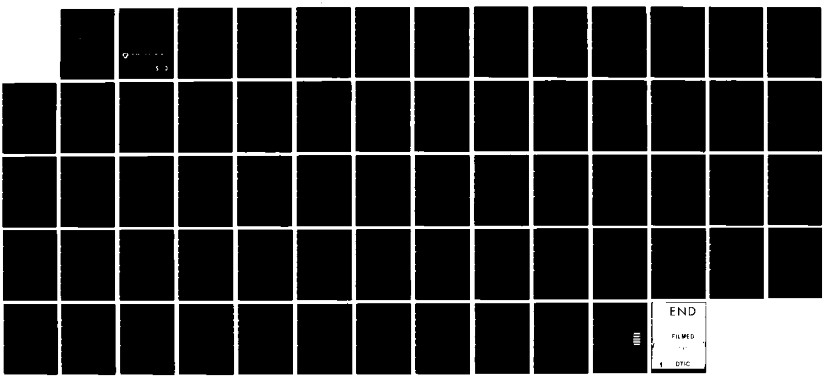

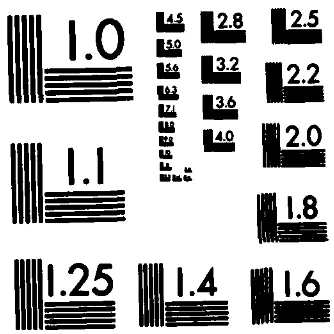

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MEMORANDUM REPORT ARBRL-MR-03230

A SENSITIVITY ANALYSIS OF THE BRL MESSAGE PROCESSING MODEL (BRLMPM) DATA INPUTS

Alan R. Downs
Morton A. Hirschberg

December 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The BRL Message Processing Model (BRLMPM) is a simulation capable of processing all messages generated by the field artillery in providing fire support to a maneuver unit. The model is a heavily input-driven, well-commented FORTRAN code characterized by great versatility in the ways it can be used. This report describes a sensitivity analysis of the inputs used in the model, critiques the model itself, and discusses future plans for revising and using the model.

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I. INTRODUCTION

The present United States Army field artillery system and its modernization for future years are constantly being critiqued by researchers, developers, and users. Such critiques generally center around two questions. 1) "What additional equipments (or resources) are needed?" 2) "How can we best use the current resources?" Past critiques led to the conclusion in the early 1970s that the Army had excellent weapon systems — howitzers with high accuracy and excellent reliability, and ammunition that was both safe and effective. Much of that capability was not fully exploited, however, since the means to acquire and locate artillery targets was provided by forward observers (FO) who did not know their own or the enemy positions to sufficient accuracy. During the 70's research and development processes resulted in a number of conceptual and fielded systems to improve the target acquisition capability. These systems include the TPQ 36/37 mortar and battery locating radars (FIREFINDER), the Standoff Target Acquisition System (SOTAS), moving target indication (MTI) radars, and remotely piloted vehicles (RPVs). Thus for the first time, the field artillery is establishing the capability to locate suitable targets quickly and accurately. In parallel development, COPPERHEAD was designed to give the field artillery the capability of engaging moving targets. Thus, it is possible to detect a moving target and guide a projectile to impact. If, however, the process takes too long, the moving target is likely to move to a location that is inaccessible to the FO and the fire mission will fail. A major thrust of current C^3 research efforts is therefore finding ways to decrease the time between a call for fire and round arrival.

Much of the impetus for looking at the soft part of the field artillery resulted from the Battleking study.[1] In September of 1974 the Assistant Secretary of the Army (Research and Development) requested the Chief of Research, Development, and Acquisition to conduct a study of the total artillery system. The objectives of the study, conducted at Ft. Sill, OK in September-November 1974, were:

1) To identify materiel concepts which promise major advances in the capability of our indirect fire, non-nuclear, artillery system.

2) To identify exploratory and advanced development efforts that warrant inclusion in the FY 76 RDT&E program.

The results of the study (not discussed here) have shaped much of the artillery system thinking that has subsequently evolved.

In 1969, the US Army Human Engineering Laboratory (HEL) located at Aberdeen Proving Ground, Maryland conducted a test at Fort Hood, Texas to determine the responsiveness of an operational artillery battalion using existing equipment. This test — the Human Engineering Laboratory Battalion Artillery Test (HELBAT) — has extended into a series of tests whose purpose

1. Office, Deputy Chief of Staff for Research, Development, and Acquisition, "Report of Artillery System Study Group (Task Force Battleking)," December 1974.

is to assess field artillery performance in various areas using traditional and developmental equipment and doctrine.[2] The various HELBATs are summarized in Table 1. The HELBAT series has been successful in providing guidance for research and development activities within the field artillery community. One conclusion reached at HELBAT 7 was that the C^3 problem was more severe than had been previously believed. It is for this reason that C^3 was made the first priority item for HELBAT 8.

Another forum for examining the field artillery in the context of a complete system has been The Technical Cooperation Program (TTCP), in particular Sub-Group W (Conventional Weapons Technology). This Sub-Group at a 1975 meeting in Canada established an action group, WAG-4 (The Total Cannon Artillery Weapon System). WAG-4 was given the mission of examining all technical and operational factors that influence the performance of tube artillery weapon systems and to report to Sub-Group W on those technologies and techniques that offer promise for significant improvements in artillery performance. WAG-4 undertook to accomplish this objective and was generally successful. Since it was established for a fixed period, however, and had no authority to exist beyond its prescribed tenure, WAG-4 was disbanded in the fall of 1978.

The final report of WAG-4[3] contained a recommendation that a new action group be formed to address artillery system technology and field experimentation and that it be charged with interfacing TTCP with HELBAT 7 and HELBAT 8 and with addressing a set of artillery system issues. The recommendation of WAG-4 was approved and a new action group, WAG-6, was formed to continue and expand the work of WAG-4. WAG-6 is due to be disbanded in the spring of 1982 when the final HELBAT 8 report is published. Although WAG-4 and WAG-6 were unable to examine all the issues felt to be important, the effort was significant in that it established common goals and methodology for addressing C^3 issues by an international forum.

A new program initiated at the US Army Ballistic Research Laboratory (BRL) involves the development of a fire support control simulator called the Artillery Control Experiment (ACE).[4] This simulator is expected to serve as a methodology to be used in developing and evaluating various alternatives in the technological, materiel, organizational, and operational aspects of fire support control. ACE is an interactive, real-time, multi-player fire support control simulator with which problems can be identified and analyzed, and potential solutions to these problems evaluated using a variety of systems and scenarios. With ACE, various hardware, software, human interface technology, and system concepts can be studied without expending the financial, time, and manpower resources needed to build complete dedicated hardware.

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2. R.B. Pengelley, "HELBAT — The Way to Tomorrow's Artillery?," International Defense Review, 1/1980.

3. Barry L. Reichard, ed., "TTCP Subgroup W (Conventional Weapons Technology) Action Group 4 (The Total Cannon Artillery Weapon System) — Final Report," November 1978.

4. Barry L. Reichard, "Fire Support Control at the Fighting Level," BRL Special Publication No. ARBRL-SP-00021, July 1981.

Plans are currently being made to use ACE to investigate some general problem areas including artillery system training, decision and control theory applications, man-machine interface requirements, and the application of artificial intelligence, gaming theory, and distributed decision-making processes to fire support control automation. Specific plans for the short term include simulating tactical fire support control materiel, e.g., the TACFIRE digital message device (DMD), studying the results obtained in HELBAT 8, and studying the new fire support officer (FSO) graphics terminal requirements. Eventually the simulation will be expanded to include higher echelon control elements.

ACE is being developed on an in-house computer system, a PDP 11/70 with UNIX operating software, but wherever possible a common programming language will be used to simplify the problems associated with its adoption and use by other organizations. Under the auspices of TTCP WAG-6 (discussed earlier in this section), ACE researchers are coordinating efforts with the United Kingdom researchers who have developed the Computer Aided Staff Trainer (a voice communications command post simulator) to the mutual benefit of both countries. The BRL Message Processing Model (BRLMPM) was initially started as a part of the ACE program but has since progressed to become a stand-alone entity. It was developed to trace the flow of messages through any communications network, but is at present configured around TACFIRE. The study described in this report is an examination of the data inputs to the BRLMPM with the objective of determining which are critical variables whose values must be specified most accurately. Section II of this report describes the BRLMPM in operational and technical terms. Section III describes the analyses that were performed and the results that were obtained in the study. Section IV presents the conclusions obtained from the study, an estimate of the strengths and weaknesses of the model itself, and a summary of future plans, dealing with both model revision and usage.

II. METHODOLOGY

The BRL Message Processing Model (BRLMPM) is a time-based simulation capable of processing all the messages generated by the field artillery in support of a maneuver brigade for any period up to 24 hours. Complete information about the BRLMPM can be found in reference 5. The model is a heavily input-driven, well-commented FORTRAN computer code that traces, step by step, the flow of field artillery related messages through the artillery communication network. The code consists of 4500 lines (2200 of which are comments) contained in a main program and 47 subprograms. The main program is short and is used primarily to direct the reading of the input data and initiating the actual simulation. The algorithms for initiating and processing messages are built into key subprograms.

In general, doctrinal rules are embodied in the computer code and are not greatly affected by the inputs. On the other hand, changes in such inputs as message rates, reflecting different equipment types, are easily handled and require little, if any, change in the computer code. BRLMPM is currently run on a CDC 7600 computer and requires from one to three minutes of computer time

5. Morton A. Hirschberg, "The BRL Message Processing Model (BRLMPM)," BRL Report being reviewed prior to publication.

to simulate an hour of battle time. The higher computer time requirements result from the large message processing time requirements associated with high mission initiation rates that result in large numbers of messages to be processed.

The missions that are processed in the BRLMPM are specified by a series of time ordered messages, each characterized by an identification of the sender, the addressee, and the message length. A mission described in this way will be referred to as a mission tree or mission profile. Missions need not conform to existing doctrine and are quite flexible. Each mission consists of from one to forty messages with provision for repeating a set of contiguous messages up to five times. In this way a complete artillery mission, including all the necessary adjust fire messages, is modeled. The model has provision for handling up to fifteen different mission types simultaneously.

The model is currently configured around TACFIRE although this is not a requirement of the model. The simulated TACFIRE message queue can hold up to 1500 messages which are currently processed on a first-come first-serve basis. All delays pertinent to the message flow are incorporated in the model and the exact value of each delay is determined by sampling from user-specified triangular distributions. Each artillery mission is performed using an assigned unit structure. A unit structure is a user specified assortment of units, links, and nets comprising the communication network. Units (FO, FIST, etc.) are connected by links which in turn make up the nets. Each net is a unique entity over which only one message can be transmitted at a time. The unit structure is contructed as an artifact of the model and is used to insure that each artillery mission is completed within the proper framework, e.g., that each FIST will be associated with his assigned FOs, etc. Unit structures are quite flexible and the user must determine the format for each. Ten unit structures containing up to fifty units each are allowed in the model. Since the model is currently limited to 150 unique units it is apparent that units can belong to more than one unit structure. The model as it is presently being used has three unit structures, each unit being found in only one unit structure except for the battalion fire direction center (BNFDC) and the brigade fire support officer (BDEFSO), which are found in all three unit structures.

The manner in which a message is processed in the BRLMPM is dependent upon a set of message processing algorithms. Some of the algorithms that are currently employed are:

a. Messages are processed on a first-come first-serve basis, i.e., the earliest generated message will always be looked at first and serviced if possible.

b. A direct link between communicating units is required.

c. A message must be in the completed state awaiting final processing time to expire before an acknowledgement message is sent.

d. The acknowledgement message must be completed before the message that triggered it is considered to be complete.

e. The next message on the mission tree will not be inserted into the message queue until its predecessor has been removed (with the exception of simultaneous messages).

Every message in a mission profile is kept for the duration of its existence in a simulated message queue. Messages are stepped through a series of stages from insertion to completion with appropriate delays calculated at each stage. The complete message history consists of:

1) sender

2) addressee

3) net

4) link

5) message type

6) message precedence

7) message priority

8) type of mission profile

9) message number in the mission profile

10) unit structure

11) mission number

12) message length

13) links used

14) message insertion time

15) message completion time

16) extraordinary delay time.

Provision has been made to record message histories as messages are completed and removed from the message queue. In this way, one can determine statistical trends in any subset of output data. For example, one can examine utilization by unit, link, net, precedence, priority, mission profile, and message length. This organization provides a practical and valuable method for analysis.

The BRLMPM is a model that is used only for the processing of messages in a network. It is not encumbered with physical phenomena, e.g., unit locations, and there are no plans to include such phenomena. The model in its present state is extremely flexible and can be used in a wide variety of scenarios. It is valuable as a stand-alone analysis tool but it could be

embedded into a large war game or simulation where other effects need to be simulated in a realistic way and depend on a good communications methodology. Such effects could include movement, firing rates, attrition, damage levels achieved, and countermeasures.

III. RESULTS

Prior to running the BRL Message Processing Model it is necessary to specify all the input values needed to control the order and magnitude of events in the model. Some of the inputs that must be specified are tied to the level of battle being analyzed: company, battalion, or brigade. Other inputs, e.g., the missions to be undertaken and the messages needed to conduct these missions, reflect the organization and doctrine of the forces. Still other inputs, e.g., the battle duration, the time resolution, and the mission initiation rate capability of the fire support team (FIST) or forward observers (FO), reflect compromises injected by the analyst to limit the outputs to manageable proportions and the running costs to reasonable levels. Finally, timing, delay, and probability data must be inserted to control the order and duration of the various events in the model. These inputs will all be discussed in this section of the report.

A. Baseline Organization Inputs

Central to any study performed with the message processing model is the communications network through which the large number of orders, requests, and acknowledgements must pass. This network consists of all the units, links, and nets within the supporting elements being addressed. In this study three supported systems are addressed: brigade, battalion, and company.

The maneuver battalion fire support network is shown in Figure 1. Each of the circles on a horizontal line represents a unit of the type indicated at the right. Each of the lines connecting two circles on different horizontal lines represents a link of direct communication. Also shown in Figure 1 are the six nets appropriate to the battalion level communications. Three of these nets are shown as the linkages between the three FISTS and their supporting FOs. The fourth net is the single link between the BNFDC and the BDEFSO. The fifth net is represented by the links between the battery FDC and the two gun sections that were considered in this study. The final net is represented by the other twelve links connecting the FISTs, BNFSO, BNFDC, and battery FDC. The brigade fire support network can be represented by placing three battalion networks side by side, removing the BNFDC and BDEFSO units from the added networks and connecting the links formerly attached to the BNFDC and BDEFSO to the corresponding units in the original battalion network. The company fire support network is obtained from the battalion fire support network by removing two of the three FISTs and their attached FOs and also removing all lines connecting the removed FISTs to other units.

Pertinent characteristics of the three fire support networks are shown in Table 2. Type 1 nets are those nets connecting each FIST to his assigned FOs. Type 2 nets connect the FISTs, BNFSOs, BNFDCs, and battery BDCs.

The type 3 net is the single link connecting the BNFDC and the BDEFSO. The type 4 nets are the battery nets that connect the battery FDCs to their gun sections.

With the communications network thus specified, it is next necessary to specify the types of missions to be employed and the messages needed for implementing those missions. Any field artillery mission can be modeled if it can be characterized by a set of successive messages. The missions to be used in exercising the BRL Message Processing Model will eventually be selected primarily from those designed for HELBAT 8.[6] Since they were not available at the time this study was initiated, two strawman missions were generated for use in most of the analyses. These missions are shown in Figure 2.

The first mission shown is a FO initiated mission that was designed by the authors. The second mission shown is a FIST initiated mission that was patterned after an unfinalized version of the TACFIRE Baseline B mission profile described in reference 6. Each line in each mission tree represents either a message or a flag to the computer and contains several items of necessary information. For example, INDEX = 6 in mission Type 1 conveys the following information. The message is sent from a FO to the battery FDC. It is a relay message (since the sender and addressee are not on the same net the message must be relayed through the FIST). It is not a simultaneous message; i.e., it has a single destination. The message is an OBSRLOC message; i.e., it provides to the battery FDC the coordinates and altitude of the forward observer which are required in the gunnery solution. Finally, the message type is "1". Except for message types 998 and 999, which are flags to the computer indicating the beginning and end of the adjust fire loop, and type 0 which is a flag indicating the end of the mission, the message type describes the length of each message. The length of each message is determined by sampling from the triangular distributions shown in Table 3. In addition, for each message shown in Figure 2, an acknowledgement is automatically generated.

B. Running Parameters

The duration of the engagement to be modeled was selected on the following basis. If a duration is selected that is too short to allow queues to build and missions to be completed, the results would be biased in that the message completion rate would seem higher and the mission completion rate would seem lower than could be expected in a real engagement. On the other hand the longer the duration selected, the more expensive the model is to run, a significant consideration given the number of runs needed to perform the intended analyses. The battle duration was set to four hours as a reasonable compromise.

The mission initiation rate was selected in the following manner. Two artillery operations experts[7] were consulted to determine a reasonable rate

6. "HELBAT 8 - Command Control Communications and Mission Profiles," U. S. Army Human Engineering Laboratory Letter Report, 15 July 1981.

7. CPT T.D. Mooney, Royal Canadian Artillery and B.L. Reichard, Ballistic Research Laboratory.

at which artillery missions could be initiated by a FO or FIST in an operational environment. Their thoughts were that a FO or FIST should probably be able to initiate and handle about four missions per hour, but that three-fourths of the FO-initiated missions are devoted to mortar operations. Thus in a brigade level engagement, the expected mission initiation rate is 4 missions/hr-FIST x 9 FIST + 4 missions/hr- FO x 27 FO x ¼ = 36 + 7 = 63 missions/hour. In like manner the mission initiation rates in battalion and company level engagements are 21 and 7 missions/hr respectively. Another model input provided is that 36/63 or 57 percent of the missions are FIST-initiated. The balance (43 percent) are FO-initiated.

The time resolution of the BRLMPM is a period of time over which the action is stopped in order to process previously generated messages and to generate new ones. In order to determine the sensitivity of the results to the mission initiation rate several runs were made using a time resolution of five seconds. The results are shown in Figures 3 through 6. Figure 3 shows the effect of the mission initiation rate on the rate at which messages are generated and completed. As can be seen, in all engagement levels an increase in the mission initiation rate results in an increase in the number of messages generated. It is apparent, however, that the number of messages generated does not keep pace with the mission initiation rate; a sixfold increase in missions initiated doesn't even double the number of messages generated. The main reason for this effect is that competition among the various subscribers for access to the limited network space can increase delays sizably. It can also be seen that the number of messages in the TACFIRE queue waiting to be acted upon increases drastically with the number of messages generated. The result of this effect is seen in Figure 4. As the number of missions initiated per hour increases, the fraction of those missions completed within four hours decreases drastically.

Another way of looking at the picture is shown in Figure 5. The four net types described earlier are characterized by the fraction of the time they are busy. Since the time each net is busy is a function of both the number of messages passing through the network and the mean message length, they are synergistic effects that must be considered in a detailed analysis of Figure 5. Several features, however, are readily apparent. First, the nets containing FO-FIST and BNFDC-BDEFSO are much more lightly used than the other two nets. This is not surprising since none of the very long messages (see Table 3) are transmitted on these nets. Second, it is apparent that the maximum effective communications load in the BTRYFDC-GUN SECTIONS and FIST-BNFSO-BNFDC-BTRYFDC nets as evidenced by the curves becoming close to horizontal is more pronounced in the large supported units than in small. Finally, as the size of the supported unit increases the usage of the FIST-BNFSO-BNFDC-BTRYFDC net increases at the expense primarily of the BTRYFDC-GUN SECTIONS net. This is also shown by the actual decrease of the latter net with increasing mission rate when a brigade is supported. This phenomenon results from the sizable TACFIRE queue that develops when the message generation rate is high, thus reducing the number of messages arriving at the battery FDC. Figure 6 shows the time and cost implications of running the message processing model with different mission rates. As can be seen, the cost of running the model increases with the mission initiation rate, particularly for company and brigade support. The reason for the somewhat different behavior of the battalion curve is not known at present.

At this point it was necessary to make a final selection of the mission initiation rates to be used in exercising the model. From Figures 3, 4, and 6 it is seen that the high mission initiation rate suggested (63 per hr) imposes a strain on the communications network and the cost of running at these rates is higher than it would be at lower rates. This case does, however, represent a valid set of running conditions, and to change those conditions in order to provide more favorable outputs could only make the communications system appear superficially better than it really is. Thus it was decided to run the analyses at the previously suggested mission initiation rates, namely, brigade — 63 missions/hour, battalion — 21 missions/hour, company — 7 missions/hour.

To provide a basis for selecting the time resolution to be used in analyzing the timing, delay, and probability data, only brigade level support was considered. A set of runs was made by varying the time resolution between 1 and 300 seconds with the results of these runs shown in Figures 7 through 9. It can be seen from Figure 7 that from a strictly financial point of view it is desirable to make the time resolution as large as possible.

Figure 8 shows that there is a spread of time resolutions over which best modeling results are obtained. On this basis, five seconds resolution would be the best choice but a resolution of ten seconds results in outputs almost as good. Greater resolutions artifically tie up the nets for longer times than needed. Smaller resolutions avoid this problem but affect the results in a manner not yet understood. Figure 9 shows that the fractional usage of the various nets is almost constant for time resolutions less than about a minute. Based on these considerations a time resolution of ten seconds was selected to perform the study.

C. Input Variables

Sixteen input variables were analyzed in varying detail depending on the apparent dependence of the results upon the specified values of the input. Each of these input variables is discussed separately in sequential subsections of this report. The minimum analyses that were performed on each input variable entailed running the model twice; once with a value of the input variable less than the baseline case; once with a value greater. If no dependence of the output upon the input was noted, the fact was stated and no further analysis was performed. If, on the other hand, output-to-input dependence was noted, a more detailed analysis including more values of the input variable, graphical analysis, interpretation, or discussion was included. In some cases sizable output changes exhibiting no obvious trends were noted when values of the inputs were changed. These cases were re-run using different random numbers and it was found that in all cases where large but apparently patternless variations in output occurred they resulted from statistical variation.

The baseline values used in exercising the BRLMPM were devised through consultation with a field artillery expert.[8] The values are not firm and in

8. Major Lawrence Morris, Ft. Sill, OK, Personal Communication, March - April 1980.

many cases, the data base upon which a selection must be made is virtually non-existent. However, for proper functioning of the model, specifying all delays that are employed is necessary, and it is no problem to change these inputs later if desirable. A list of the baseline values of the 16 input variables is presented in Table 4.

The runs performed and the results obtained are presented in Table 5. This table is the heart of the analyses that were performed and provides a starting point for the discussions that follow. The INPUT ADDRESSED column lists the variables that were varied in the study. CONDITIONS ADDRESSED shows the values of those inputs for which data runs were made. All times and delays are expressed in seconds. The balance of the table contains the results of the data runs. The MESSAGES AND MISSIONS columns describe the situation at the end of four hours. The fraction of time the various nets are busy can be interpreted based on Table 6. The baseline runs are included in each table entry and can be found quickly by noting that in this run the fraction of the time that the relays are busy is 0.1225. Table 5 will serve as a guide to the discussions that follow. Selected figures are also included to highlight some of the features in Table 5. These figures are shown as smooth curves through the data points that in most cases are also plotted. From the spread of the data points a feeling can be obtained about the statistical regularity of the data.

1. Computer and Message Failure:

When a message is generated but never arrives at its destination, the cause can be either a computer failure or something else. When computer failure is not the cause, the result will be referred to as a failed message. Computer and message failures were treated together since their effect is very similar and the input time delays apply to both. As can be seen in Table 5, three data sets were generated by sequentially varying the value of each input variable while holding the other two constant. When the computer failure probability was doubled or halved, no recognizable trends in the outputs were apparent. The probable reason for this effect is the very low probabilities involved. The probability of message failure, being large, has a significant effect on the outputs as shown in Figure 10.

The surprising results shown in this figure (a lessening in the reliability of one component results in the improved performance of the system as a whole) is easily explained by noting that increasing the message failure rate increases the speed of processing of those messages that do not fail. Better ways of accomplishing the same purpose will be discussed in the SUMMARY Section of this report.

Increasing the delays resulting from computer or message failure is seen in Table 5 to affect only the mission completion rate. The manner of affecting this output is as to be expected; increased delays slow down the processing of the artillery missions. The effect on the other outputs is not discernible since any trends are masked by statistical variations.

2. NAK Sequence:

Where a message is addressed to the BNFDC, three mutually exclusive events occur. First, the message can be received and acknowledged by TACFIRE. Second, the message may not be received by TACFIRE. This event is referred to as a message failure. Finally, the message may be received by TACFIRE but not acted upon. This event can occur when there is something wrong with the message, e.g., it is not properly authenticated. This event is referred to as a NAK. In the normal running of the model, a message may be NAKed or not depending on a random number drawing, and if it is NAKed the first time, there is an additional liklihood that it will be NAKed on subsequent transmissions. If the same message is NAKed four times, the transmitting unit is removed from the subscriber list (i.e., may not transmit or receive messages) for a prescribed time. In this study, a specified number of NAKs apply to each message. Thus no units are removed from the subscriber list except in the final case. (Additional analysis of the NAK sequence problem will be found in Section III. C.14.)

The results of the NAK sequence analysis are shown in Figure 11. The "x"s on the upper and lower graphs represent the baseline case in which the number of NAKs is determined by a random number drawing. It can be seen in the figure that the effect of increasing the number of NAKs is much greater on the mission completion than on message processing in TACFIRE. This is logical since increasing the NAK rate does not affect the rate at which missions are generated but does slow down the rate at which those missions flow through the model and therefore the rate at which messages both enter and leave the TACFIRE queue.

When each message is NAKed four times an abrupt change in model output occurred. The number of missions generated was 252. This was consistent with the input mission initiation rate of 63 per hour. The number of messages generated was also 252 showing that when all messages were NAKed, each mission was hung up on the first message. The fact that no missions were completed is also consistent with this. Since no messages were processed by TACFIRE, the usage rates on two of the nets were zero. Net 2 had a low usage rate due to the low number of messages generated. Net 1, on the other hand, showed higher usage than normal due to the number of times the first message of the FO initiated missions had to be repeated.

3. Human Delay:

The effects of human delays in the message processing model were investigated by halving and doubling the baseline values for this variable. No noticeable trend was noted in the message or mission outputs. Any trends noticed in the net usage times were so slight as to be indistinguishable from normal statistical variation. Human delays were therefore not investigated further.

4. Computer Delay for Fire Mission Processing:

The effects of fire mission processing delays were addressed by dividing by three and tripling the baseline values of this variable. The results are shown in Figure 12. As would be expected, increasing the delay time

resulted in a decreased ability of the system to process messages and complete missions. The amount of the decrease was not large but definite.

5. Non-Fire Mission Processing Delay:

The effects of non-fire mission processing delays were addressed by dividing by three and tripling the baseline values of this variable. No noticeable trends were found in the message or mission outputs. The net usage outputs showed that an increase in the delays resulting from non-fire mission processing resulted in a redistribution of the message load on the net types; specifically the battery net message traffic increases at the expense of the FO-FIST and BNFDC-BDEFSO nets. The reason for this effect is not known at present.

6. Delay Due to Relay Through Fist:

The effects of delays resulting from relaying all messages between the FOs and other units through the appropriate FIST were addressed by dividing by three and tripling the baseline delay. Although large variations in the message and mission outputs were noted, they seemed to form no definite trend and thus can be attributed to statistical variation. A slight decrease in the TACFIRE net loading and a substantial decrease in the battery net loading resulted from an increase in relay delays. The former could easily result from statistical variation, but the latter appears to be a definite trend, the reason for which is not known at present.

7. Waiting Time in Message Queue:

The waiting time in the message queue is a delay time in excess of that time required for a message to advance in the queue until it can be acted upon. The baseline delay was halved and doubled to determine the effect of this variable. The results showed large, but apparently patternless, variations. This variable was therefore not addressed further.

8. Delay in NAK Processing:

The effects of NAK processing delay time were addressed by halving and doubling the baseline values of this variable. Although no trends are apparent in the results, an oddity was noted in that the fraction of messages remaining in the queue was lower than would normally be expected and the fraction of missions completed was higher than would be expected in both the halved and doubled cases. Due to the magnitude of the differences, this effect is probably not due to statistical variation, but its cause is not known at present.

9. Handoff:

Handoff is the process whereby a mission is handed off to another battery if the first battery assigned to fire that mission is unable to do so. This process is represented in the model by a probability that handoff will occur and the resultant delays if it does occur. The results of this parametric study are shown in Figure 13. It is apparent that as the probability of handoff increases the message queue length increases and the

mission completion rate decreases. The dependence of the rate of increase or decrease on the amount of the delay is not readily apparent. It is apparent, however, from the lower graph on Figure 13, that if the probability of handoff is low, the mission completion rate increases with increasing delay, whereas if the probability of handoff is high, the mission completion rate decreases with increasing delay. These results can be interpreted by noting that for low handoff probability, long delays in one mission can permit messages from other missions to be transmitted quickly, thus increasing the probability of those missions being completed during the four hour battle period. For high handoff probability, however, long delays result in a general slowing down of the rate at which missions are completed.

10. Preamble Time

The preamble to a message is a set of identifiers that characterizes the transmitter and assures that the following message is real rather than a decoy. As with the actual message, the preamble takes a certain amount of time to transmit and be processed. This time is referred to as the preamble time. In order to address this variable, its baseline values were both halved and doubled. No observable dependence of output or preamble time was found so no further analysis of this variable was undertaken.

11. Mission Stoppage:

The stopping of an artillery mission is the process wherein the field artillery structure completely suspends all operation of that mission for a particular time; all units stop tracking, transmitting, firing, etc. in support of that mission and direct their attention to other missions. The effect of mission stoppage was addressed by varying the probability of stopping by a factor of five and the resulting delay by a factor four, both centered on the baseline values. The resulting variations were surprisingly large, but seemingly devoid of trends, and can be attributed to satistical variation.

12. Turn-On Time:

The turn-on time for a transmitter is the warm-up time between the pushing of the button and the start of the preamble and is processed in the model as a delay. This delay was varied by a factor of 25 centered on its baseline value. No significant trends were noticed in the data so the turn-on time was not investigated further.

13. Gun Setup Time:

The gun setup time is the time required to re-aim the guns after receiving new quadrant and elevation orders from the battery FDC. The resulting delay was divided by 30 and multiplied by 3 and run in the model. No noticeable trends in the message queue length or mission completion rate were noted. This feature was a result of the fact that even with very long setup delays the delay time is efficiently used by transmitting messages pertaining to other missions. It is also to be noted that the usages of the FO-FIST and battery nets increase with increasing setup time. This variable was not investigated further.

14. NAK Sequence and Resulting Delay:

This analysis differs from that in Section III.C.2. in that the previous analysis specified the number of NAKs each message received. The analysis in this subsection still depends on statistical sampling, but the probabilities of given numbers of NAKs are readjusted to accommodate the assigned probability of four NAKs since this is the flag that removes the transmitting unit from the subscriber list and imposes a delay. The breakdown of the NAK probabilities is shown in Table 7. As can be seen, values of P(4 NAKs) were selected and the other probabilities were assigned so as to keep them in as constant a ratio as possible consistent with the input requirements of the model.

Various difficulties were encountered in analyzing the NAK sequence and resulting delays. A series of curves was drawn in an attempt to relate the message, mission, and net usage outputs to various combinations of the input variables. In all cases the scatter of the data points was large and in the case of the mission completion rate as a function of delay time for several values of P(4 NAK), the results were almost impossible to interpret. Two conclusions can be drawn, however. When P(4 NAK) increases with a constant delay, the fraction of missions completed decreases to zero at the point where P(4 NAK) = 1.0. Simultaneously the fraction of messages remaining in the TACFIRE queue increases slightly to some undefined point after which it drops to zero at p(4 NAK) = 1.0. It is apparent that the probability of non-acknowledging a message and the resulting delay should be kept as low as possible, but the effects of doing so are not readily apparent in the Message Processing Model.

15. Net Access Delay Time:

The next access delay time is a TACFIRE imposed delay between the time a message is injected into a net and the time a message is routed to its destination. The value of this delay as shown in Table 5 requires some explanation. Consider the second data line in the appropriate section of the table. This line states that ninety percent of the time the delay is 0.2 seconds. The other ten percent is divided intc 98 equal pieces (each with a value of 0.1/98) representing 0.4, 0.6, 0.8,.....19.8 seconds. This mean delay time is then given by:

$$(\bar{T}) = 0.9x + \frac{0.1x}{98} \sum_{i=2}^{99} (i) = 5.95x$$

where x is the ninety percent time delay. Thus in the aforementioned case the mean delay is 5.95 x 0.2 = 1.190 seconds.

When the brigade support version of the Message Processing Model was run, the results appeared sufficiently dramatic that the company support version was also run. The results of the message and mission analyses are shown in Figure 14. The baseline values in each graph are represented by an expected delay of 2.975 seconds. It is apparent that for brigade support the mission completion rate is very sensitive to the net access delay time. For example, if the expected delay time is three seconds, the mission completion

rate is 0.25, representing 63 missions in four hours. If the net access delay time is reduced to two seconds, the mission completion rate rises to 0.43. Thus the number of fire missions that can be completed within four hours rises to 108. Less dramatic but in the same vein is the company level support. A decrease in the delay from 3 to 2 seconds increases the number of completed missions from 12.46 to 13.30.

The net usage in the two cases is shown in Figure 15. It is seen that in general there is an increase in net usage as the net access delay time is increased. Exceptions to this are seen in the battery and TACFIRE nets for large expected delays in brigade support. This feature results in the very low mission completion rates shown in Figure 14; i.e., the delays early in the mission result in excessive TACFIRE queues that in turn reduce the message and mission completion rates. When the delays are increased the problem is compounded. Also of interest, but no surprise, is the difference between the brigade support and company support outputs. As the size of the supported organization decreases, the usage of the artillery nets also decreases, the effect being least pronounced in the TACFIRE and battery nets where the message overloading is most severe. The conclusion that can be drawn from this analysis is that shortening the net access delay time to a value less than 2 or 3 seconds results in highly improved field artillery mission performance.

16. Adjust Fire Loop:

The mission profiles shown in Figure 2 can be divided into two parts. The messages preceding type 998 and those after type 999 represent the normal flow of the artillery mission and are repeated once and only once. The messages situated between types 998 and 999 represent the adjust fire loop and are repeated as often as necessary to assure that the artillery fire will impact within an allowable distance from the target. In the Message Processing Model this adjust fire loop may be traversed from one to five times based on a random number drawing. One way to reduce the number of artillery messages required to complete a fire mission is to reduce the number of times the adjust fire loop is traversed. The effect of the number of times this loop is repeated is shown in Figure 16.

The x's on the upper and lower graphs represent the baseline case in which the number of adjusts is determined by a random number drawing. As can be seen, reducing the number of adjusts results in improved artillery mission performance in supporting both brigade and company maneuver elements. For example, in supporting a brigade the ability to perform first round fire for effect missions almost triples the mission completion rate of the field artillery. The performance of the field artillery in support of company maneuver elements is higher to begin with so reducing the number of adjusts does not lead to as dramatic results. Even so, a first round fire for effect capability increases the mission completion rate by 40 percent.

D. Mission Profiles

Since the HELBAT 8 mission profiles described in reference 6 were available prior to the end of the study it was decided to perform runs with some of them. Those selected for analysis are the profiles for which technical fire control (calculation of gun orders) is performed at the battalion FDC.

Five of the new mission profiles meet this criterion and are described in Table 8. These mission profiles were coded and run in the BRLMPM in place of the baseline profile. The results are shown in Table 9.

Several features in this table are of particular interest. First, the message and mission completion rates appear to be lowest for the mission profiles in which the most messages are generated. This is the result that would normally be expected. Second, the usage of net 4 seems to be directly proportional to the mission completion rate. This is as it should be. Third, the mission profiles used for "smart" munition delivery result in lower mission completion rates than do those for conventional munition delivery. The reason for this phenomenon is the larger number of messages needed to process a "smart" munition mission. Finally, when tactical fire control is performed at brigade, the usage of the BDEFSO net is quite high. As a result, the BDEFSO net becomes the overburdened one and the usage on the TACFIRE net and the mission completion rate both drop significantly. Better performance in this case could be expected if the BDEFSO was tied directly to units other than the BNFDC.

E. Validation of Output

Some of the results of running the BRLMPM were compared to the results obtained in a study[9] performed at the US Army Materiel Systems Analysis Activity (AMSAA) on TACFIRE communications. The inputs to the BRLMPM were substantially modified in order to perform the comparison. The modification consisted of reducing or deleting certain delays, redefining the mission profile, and changing the message length characteristics in order to provide as close a comparison as possible. The results of the comparison are shown in Table 10.

The headings in this table can be interpreted in light of the following comments. The lines labeled "Baseline" are runs made with BRLMPM using the baseline values listed in Table 5. The columns labeled "AMSAA" represent data that were extracted directly from reference 9. The columns labeled "BRL 1" and "BRL 4" represent runs of one and four hours respectively with the BRLMPM using revised data inputs for direct comparison with the AMSAA results. It is obvious that running the BRLMPM with the AMSAA inputs results in higher mission completion rates and lower mission durations than were found when the BRL inputs were used. In direct comparison of the outputs from the two models it is obvious that significantly better TACFIRE performance is obtained using the AMSAA model. This difference can probably be accounted for in full by the single sizable difference remaining between the two studies. In the AMSAA study, the number of missions being conducted at any one time is constrained. In the BRL study no such constraint existed. As a result the time a message has to wait in the queue for processing is significantly longer in the BRL study than in the AMSAA study. The result is a higher mission duration and a lower mission completion rate in the BRL study.

9. Kenneth B. Matthews, Jr., "Supplement to AMSAA Independent Evaluation of the Tactical Fire Direction System Communications," AMSAA Unpublished Report, 1980.

IV. SUMMARY

The study that is described in this report was an analysis of the sensitivity of the outputs of the BRLMPM to changes in the values of the input variables. The results obtained in the study are described in detail in Section III and are summarized in Table 11. Three of the seventeen variables are seen to be of particular importance. The excessive number of NAKs is seen to influence the results in two ways: imposing delays and tying up resources by having to repeat a message and by excessive delays encountered when a message is NAKed four times. The best way to improve this situation is to reduce the number of NAKs either by improved radio communication or through an improved priority scheme wherein acknowledgements are processed more rapidly. Even slight reductions in the net access delay can pay large dividends in the completion rates of both messages and missions since this effect penalizes all messages and acknowledgements in an artillery mission. Sizable gains can be achieved also by reducing the adjust fire requirements. A usable first round fire for effect capability would not only reduce the number of messages in a typical artillery mission by half, but would also, although not addressed in this study, result in considerable savings in ammunition and improved responsiveness.

The effect of message failure (Section 3.C.1.) was somewhat surprising, but it should be noted that while increasing the message failure rate may well increase the mission completion rate, a better way to accomplish the same purpose would be achieved by incorporating a priority scheme into the message processing mechanism. Even this procedure is no cure-all as it is apparent that TACFIRE is overworked in trying to satisfy the demands of full scale brigade support. This is shown in Figure 17. The top half of this figure demonstrates that there is an optimum range in the number of missions initiated for which TACFIRE operates effectively. At lower rates, the full TACFIRE capability is not being utilized; at higher rates, the entire system including TACFIRE is being overworked. It is also apparent that the total number of missions generated is not the only factor that influences the mission completion rate. The size of the supported organization is also important since many of the delays have nothing to do with TACFIRE. The bottom half of Figure 17 demonstrates that there is generally an optimum rate at which a FO of FIST should initiate artillery missions. The optimum is most apparent in brigade support where there is a large number of FOs and FISTs competing for the fixed field artillery resources.

The study that has been described in this report has two aims. First was the determination of the critical variables in analyzing the field artillery C^3 problems in order to limit the scope of future analyses. Second was a critique of the strengths and weaknesses of the BRLMPM. These aims will be discussed in turn. The greatest strength of the study is that each variable was addressed individually so that its effects could be individually determined. Another strength of the study is that it took into account in pertinent cases the size of the maneuver element supported. Finally, several outputs were considered in order to uncover information about missions, messages, and net usage.

Several weaknesses to the study should also be noted. First, there is often the lack of an adequate data base upon which to depend in selecting the baseline values of the variables addressed in the study. Second, a number of possible synergistic effects were not addressed due to time and cost constraints. For example, the effect of varying the number of adjusts in conjunction with the "smart munition" mission profiles was not addressed. Finally, additional studies which could not be performed in the available time would have uncovered additional areas for future study. Examples include analyzing different artillery communication networks, considering selective attrition of various units, and considering a time-dependent mission initiation rate to simulate surges in fire support requirements.

The BRLMPM also has its own characteristic strengths and weaknesses. The first strength of the BRLMPM noted was its overall versatility. The model can be used to address a wide variety of communication systems since it is not tied to any particular organization structure, command structure, mission type, etc. Second, all delays are individually incorporated in the model; thus a change in one delay can be made directly without the need for determining in advance the synergistic interactions to be expected and making necessary modifications. Third, in many cases where the model does not address features that might be of interest, provision is built in to include those features with a minimum of model revision. For example, provision has been made for changing communication equipment resulting from breakdown although it is not used at present. Further, it is easy to handle message relays in the BRLMPM. Adjustable delays are built into the model for this purpose. Finally, adjust fire loops and acknowledgements are easily handled.

There is also one weakness in the BRLMPM that was found in this initial study. The ability to assign priorities and precedences to the various messages and missions was not possible. Provision was built into the model to do this, but the model must be revised to accommodate this process. Although not a model weakness, it is often difficult to tell from a set of runs whether differences result from real trends in the output or from statistical variation. Additional runs can usually answer the questions, but since the runs are relatively expensive to make, it is not always convenient to do so. This feature can be used to advantage in that successive runs made with the model can be analyzed statistically if desired in some cases.

Additional modifications to the BRLMPM are currently being planned. First, the model will be modified so that priorities and precedences can be handled automatically. This is a rather minor model modification. Second, model revisions will be made to make it easier to address systems other than TACFIRE, e.g., allow technical fire planning to be performed by the FIST or battery rather than just at the BNFDC. This will simplify addressing such systems as AFATDS. Finally, link switching algorithms will be developed and incorporated in the BRLMPM to facilitate the study of such systems as the Position Locating and Reporting System (PLRS) and the Joint Tactical Information Distributing System (JTIDS) and the PLRS/JTIDS hybrid (PJH).

Additional studies with the BRLMPM are being planned. The studies will be structured to determine possible improvements in alternative ways of providing fire support communication or to provide validation of the results

obtained by using the model. A major validation will be achieved by re-running some of the mission profiles used in HELBAT 8 and comparing the results obtained with the BRLMPM with those obtained in the field. Runs will also be made with revised network structures and mission profiles used in HELBAT 8 and comparing the results obtained with the BRLMPM with those obtained in the field. Runs will also be made with revised network structures and mission profiles to see what advantages result when simplifications can be made, e.g., reduce the number of adjusts needed prior to a fire for effect order. Once the mechanism for handling priorities is built into the BRLMPM, a study will be made to determine the best way to utilize them. Possible schemes might include the processing of acknowledgements ahead of other messages and rapid processing of messages in the earliest started missions ahead of those started later. Additional work is planned to support the Division Support Weapon System (DSWS) concept. This work will be in support of the C^3 task and will address such features as nominal and worst case analysis, selective attrition of various units, and the incorporation of AFATDS and PJH into the field artillery.

In summary, the BRLMPM is currently running and is designed around TACFIRE. Modifications are being made to extend the model's capability to address other systems. A baseline analysis of the model has been performed and additional analysis is planned to determine exactly how well the model simulates the actual happenings in a field artillery organization. Heavy use of the model is planned in the future and some initial studies are currently being organized. The authors would welcome any feedback about the model or the activities in which it will be used. They may be contacted at the following mailing address.

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ACKNOWLEDGEMENT

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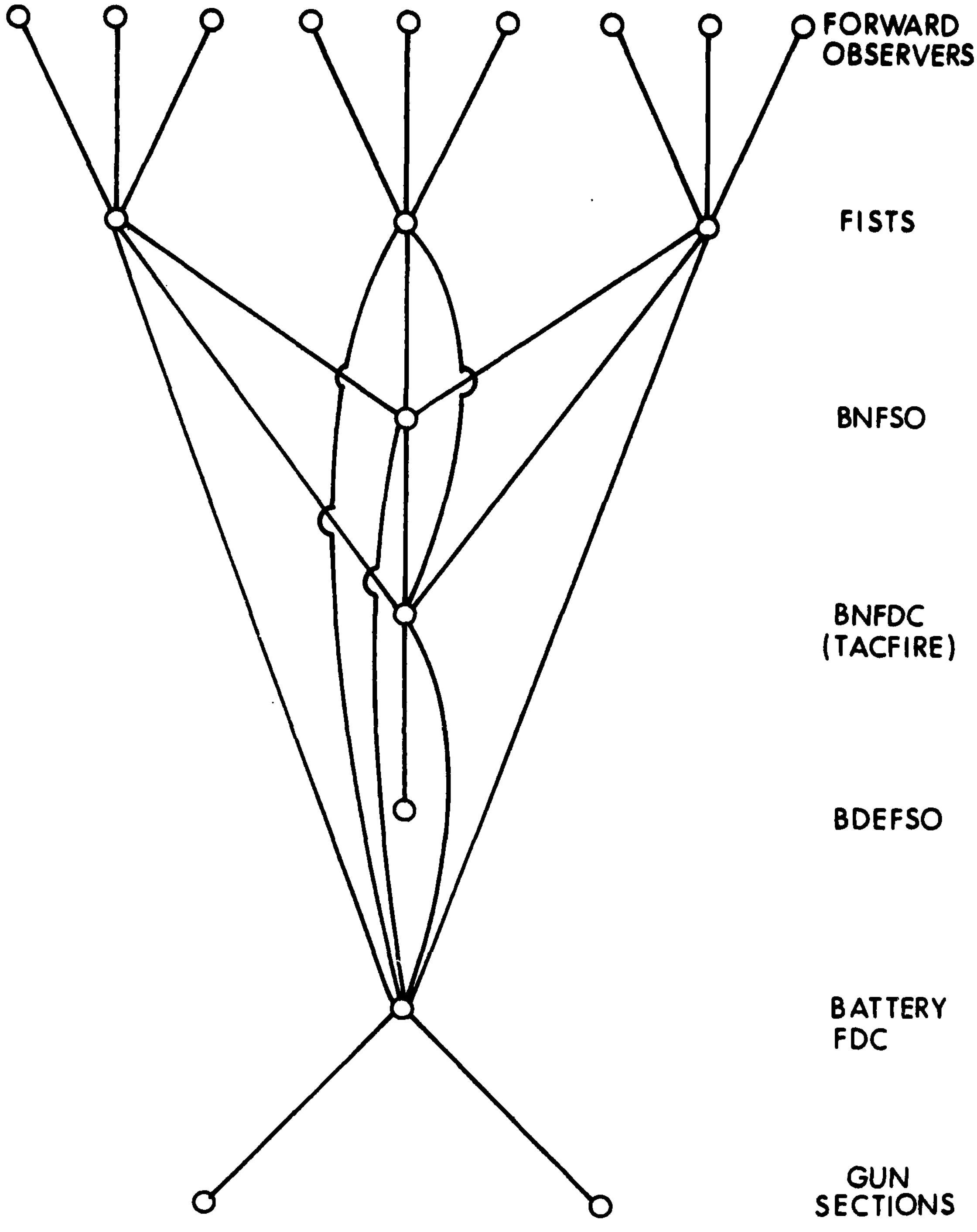


Figure 1. Communication Network of a Field Artillery Battalion

MISSION TREE FOR MISSION 1
THERE ARE 26 MESSAGE PARTS

INDEX	SENDER	ADDRESSEE	RELAY	SIMUL	MSG ID	MSG TYPE
1	FO	FIST	NO	NO	DELAY	1
2	FIST	BNFSE	NO	NO	DELAY	2
3	BNFSE	BATT	NO	NO	BTRY	6
4	BATT	FIST	NO	NO	BTRY	6
5	FIST	FO	NO	NO	BTRY	1
6	FO	BATT	YES	NO	OBSRLOC	1
7	FO	BATT	YES	NO	FRGRID	1
8			NO	NO		998
9	BATT	GUNS	NO	YES	WR	3
10	BATT	FO	YES	YES	MTO	1
11	GUNS	BATT	NO	NO	READY	6
12	BATT	GUNS	NO	NO	FIRE	1
13	GUNS	BATT	NO	NO	SHOT	1
14	BATT	FO	YES	NO	SHOT	1
15	BATT	FO	YES	NO	SPLASH	1
16	FO	BATT	YES	NO	SAGRID	1
17			NO	NO		999
18	BATT	GUNS	NO	YES	WR	5
19	BATT	FO	YES	YES	MTO	1
20	GUNS	BATT	NO	NO	READY	6
21	BATT	GUNS	NO	NO	FFE	1
22	GUNS	BATT	NO	NO	SHOT	1
23	BATT	FO	YES	NO	SHOT	1
24	GUNS	BATT	NO	NO	COMPLETE	4
25	BATT	FO	YES	NO	COMPLETE	1
26	END		NO	NO		0

Figure 2. Mission Profiles Used in the Study

MISSION TREE FOR MISSION 2
THERE ARE 25 MESSAGE PARTS

INDEX	SENDER	ADDRESSEE	RELAY	SIMUL	MSG ID	MSG TYPE
1	FIST	BNFDC	NO	NO	REQ FM	3
2	BNFDC	BATT	NC	YES	REC	1
3	BNFDC	BNFSE	NO	YES	RFAF	2
4	BNFDC	FIST	NO	YES	MTO	1
5	BNFDC	BDEFSO	NO	YES	REC MOI	4
6	BATT	GUNS	NO	NO	WR	3
7	GUNS	BATT	NO	NO	READY	6
8	BATT	FIST	NO	NO	SHOT	1
9	FIST	BNFDC	NO	NO	FRGRID	1
10			NO	NO		998
11	BNFDC	BATT	NO	NO	REC FM	3
12	BATT	GUNS	NO	NO	WR	3
13	GUNS	BATT	NO	NO	READY	6
14	BATT	FIST	NO	NO	SHOT	1
15	FIST	BNFDC	NO	NO	SAGRID	1
16			NO	NO		999
17	BNFDC	BATT	NO	NO	REC FM	3
18	BATT	GUNS	NC	NO	WR	5
19	GUNS	BATT	NO	NO	READY	6
20	BATT	FIST	NO	NO	FFE	1
21	GUNS	BATT	NO	NO	COMPLETE	4
22	FIST	BNFDC	NO	NO	REC EOM	5
23	BNFDC	BATT	NO	NO	EOM	6
24	BATT	GUNS	NO	NO	EOM	6
25	END		NO	NO		0

Figure 2. Mission Profiles Used in the Study (Cont'd)

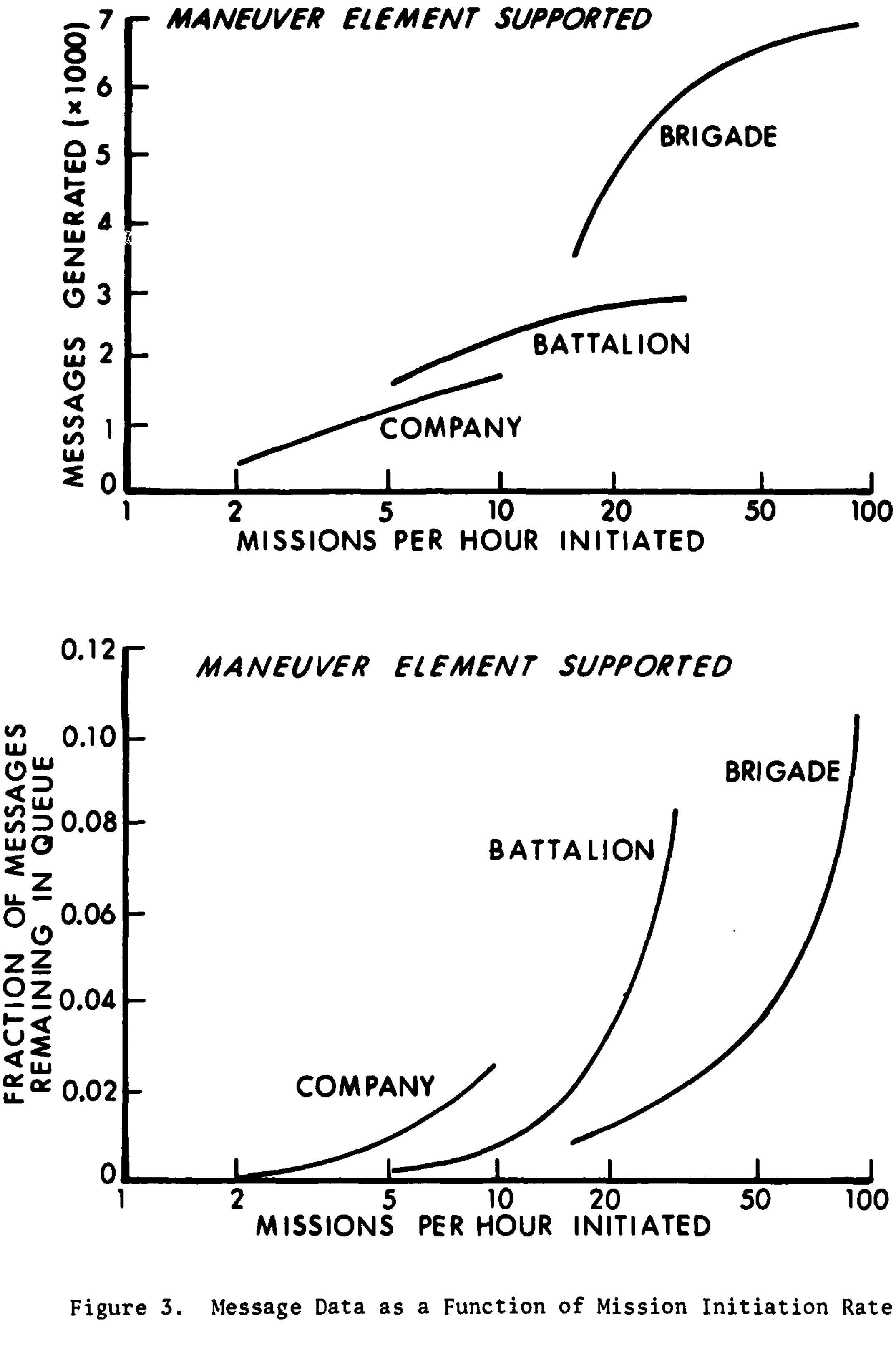


Figure 3. Message Data as a Function of Mission Initiation Rate

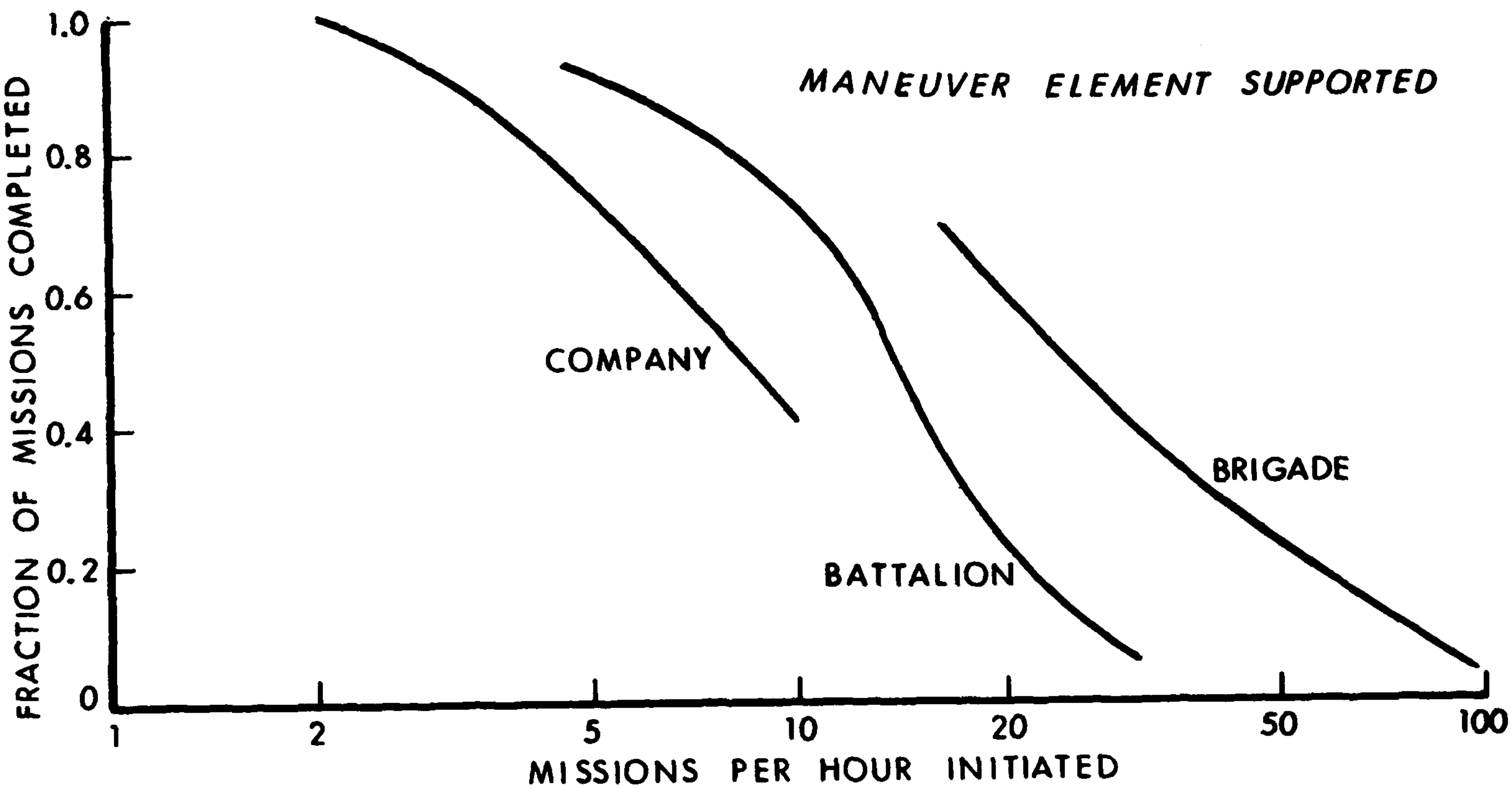


Figure 4. Mission Data as a Function of Mission Initiation Rate

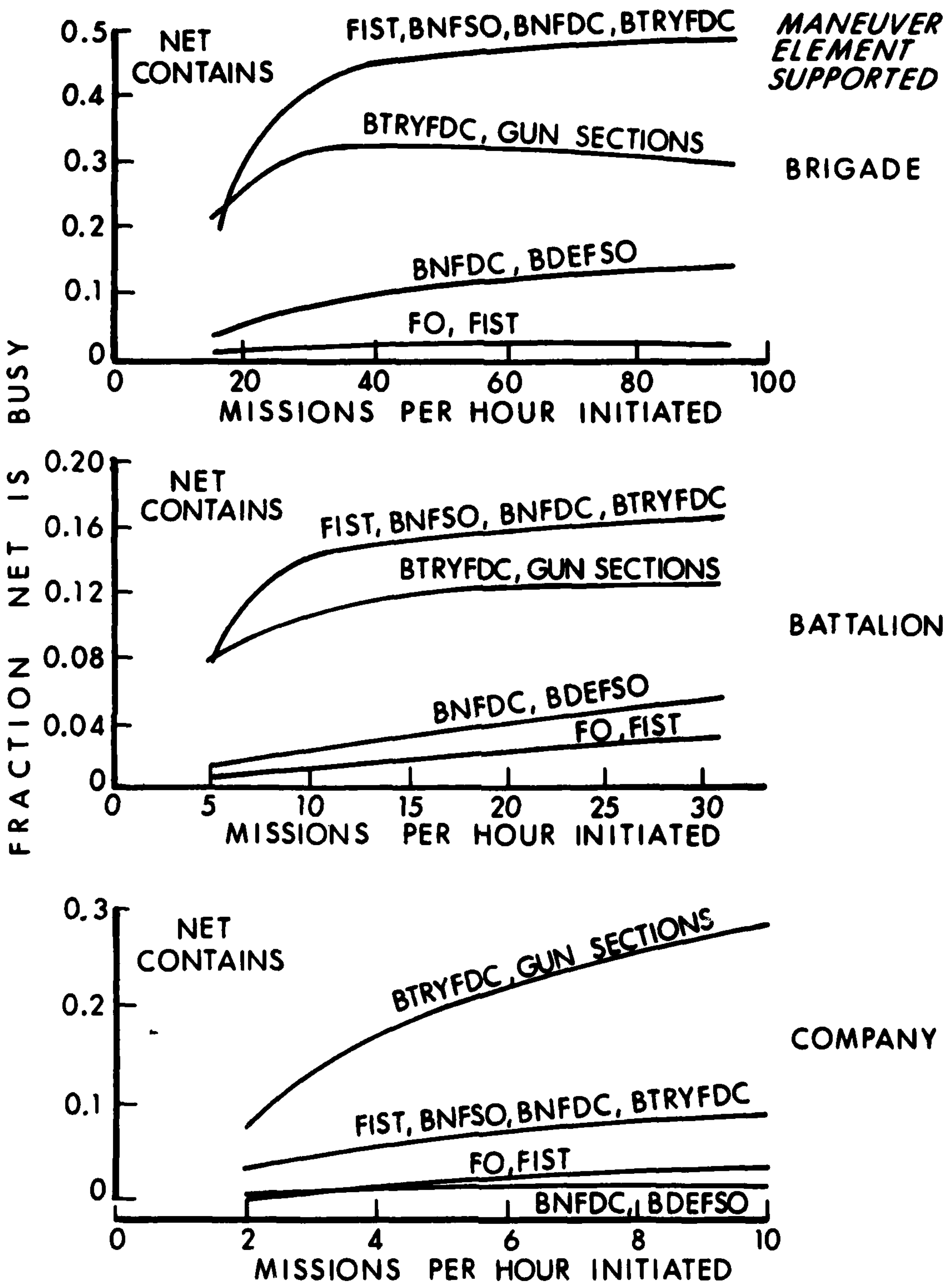


Figure 5. Net Usage as a Function of Mission Initiation Rate

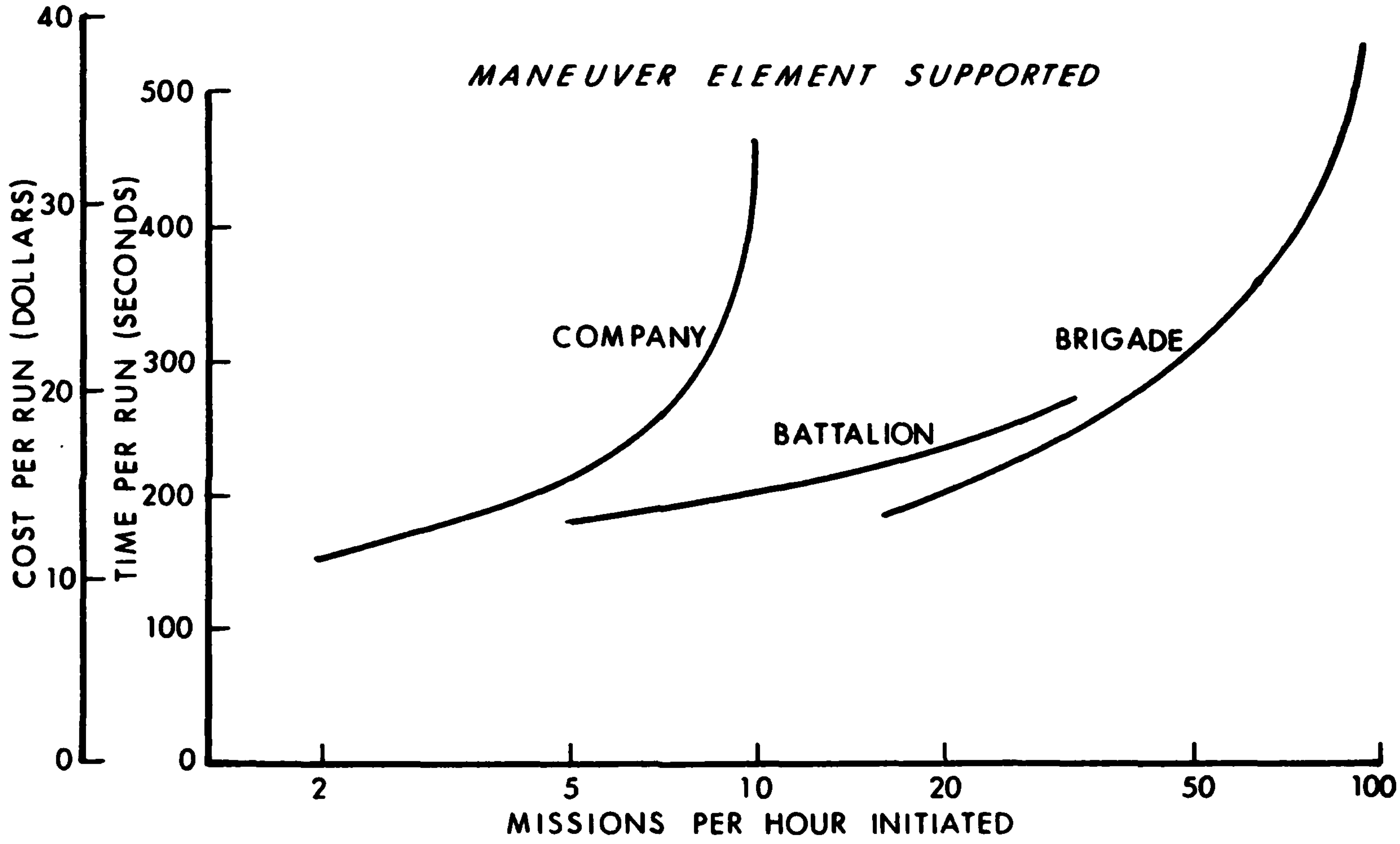


Figure 6. Running Cost as a Function of Mission Initiation Rate

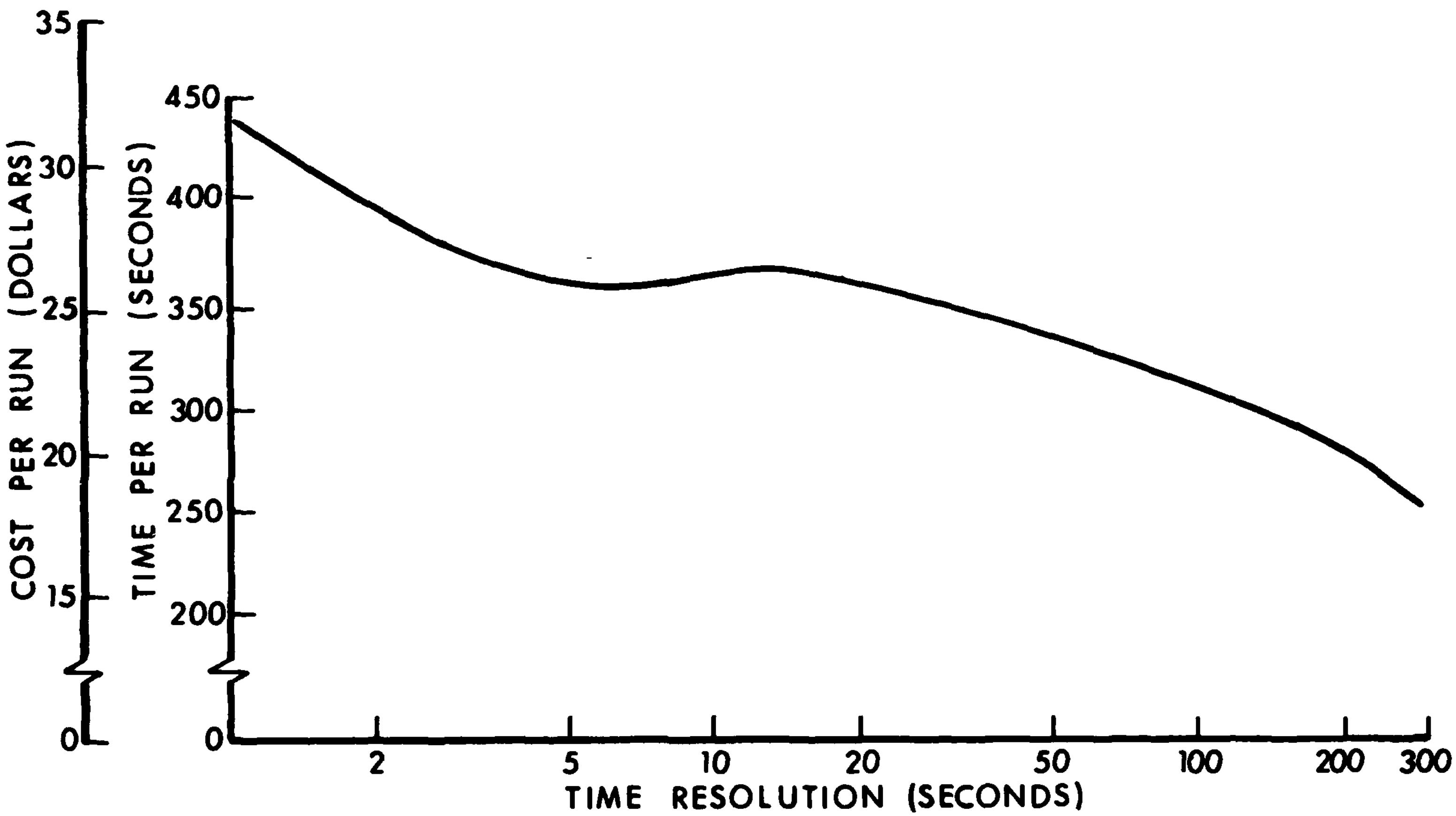
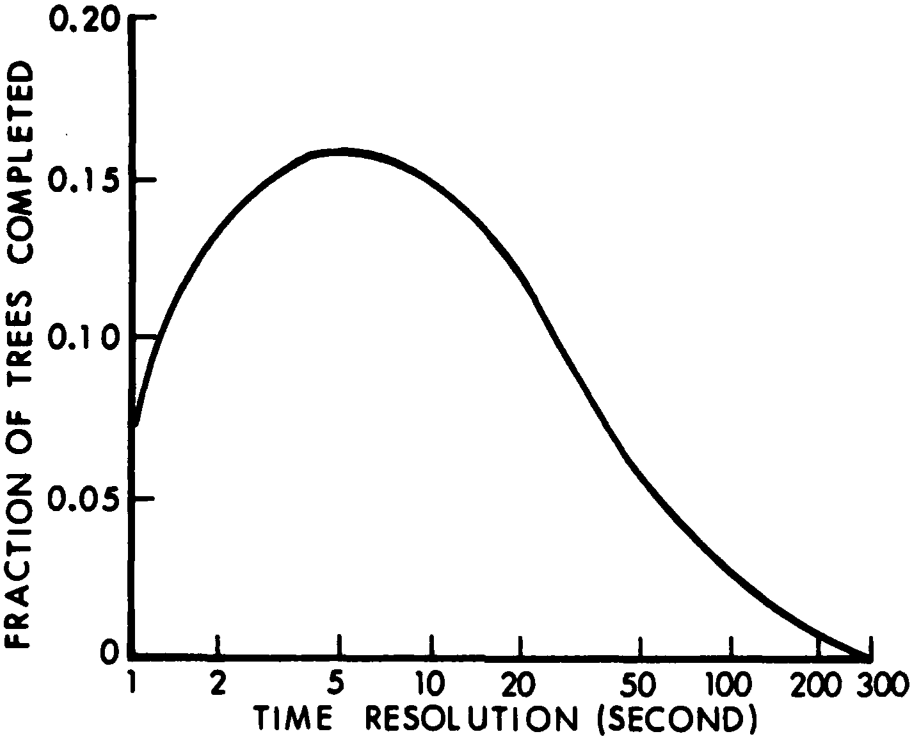


Figure 7. Running Cost as a Function of Time Resolution



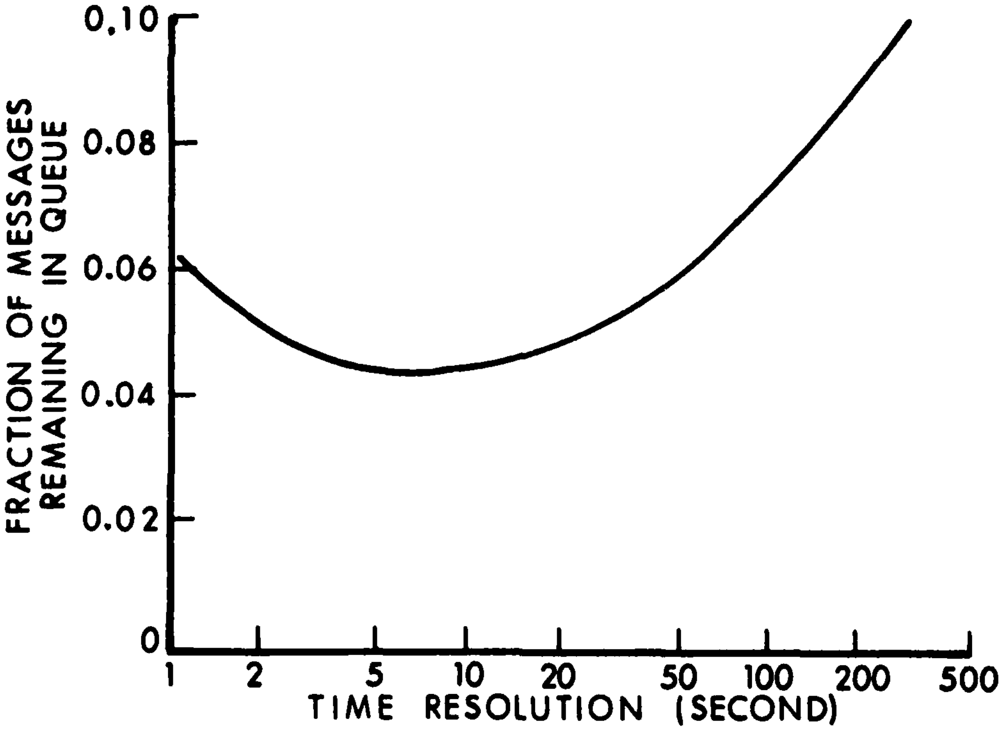


Figure 8. Message and Mission Data as a Function of Time Resolution

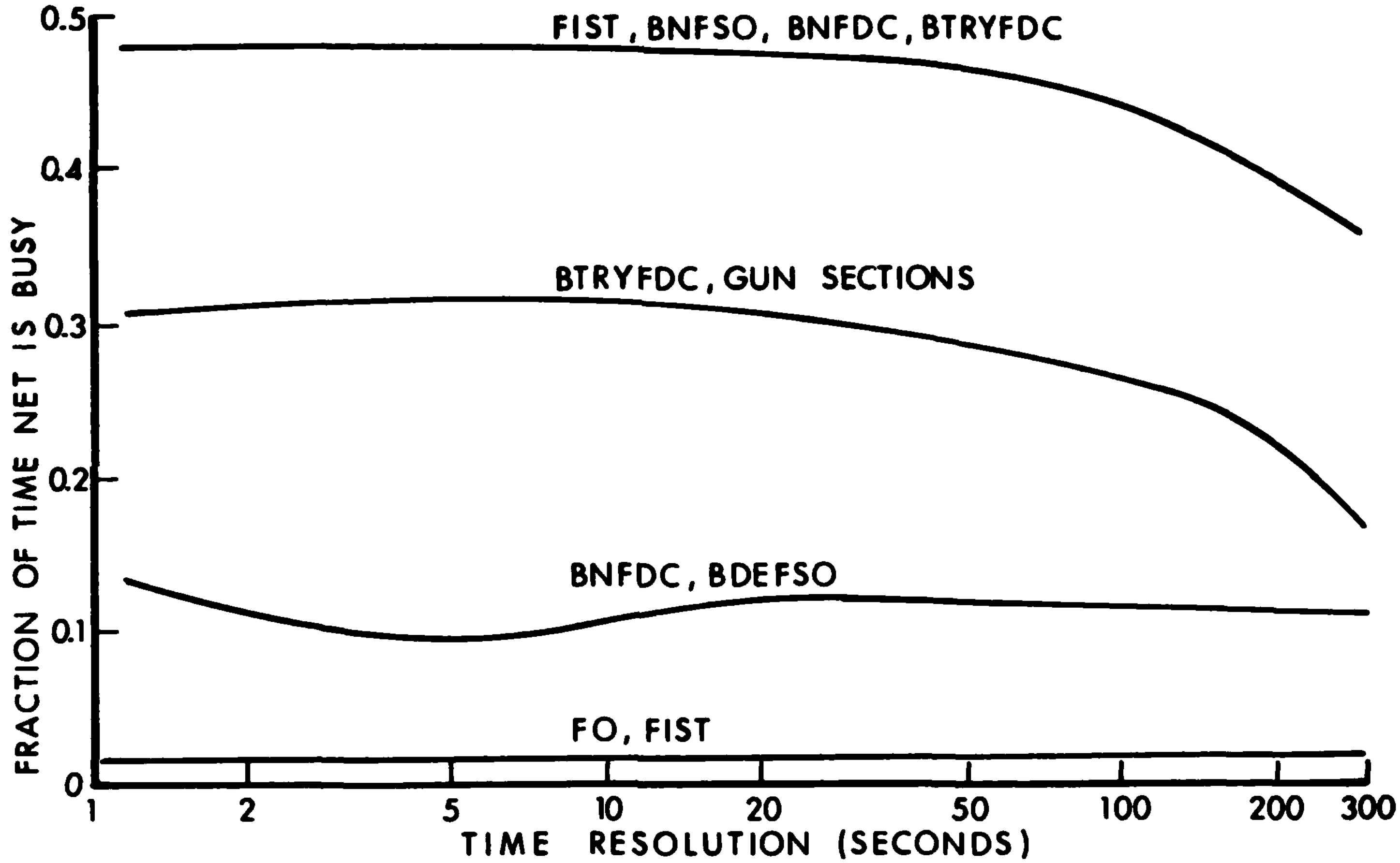


Figure 9. Net Usage as a Function of Time Resolution

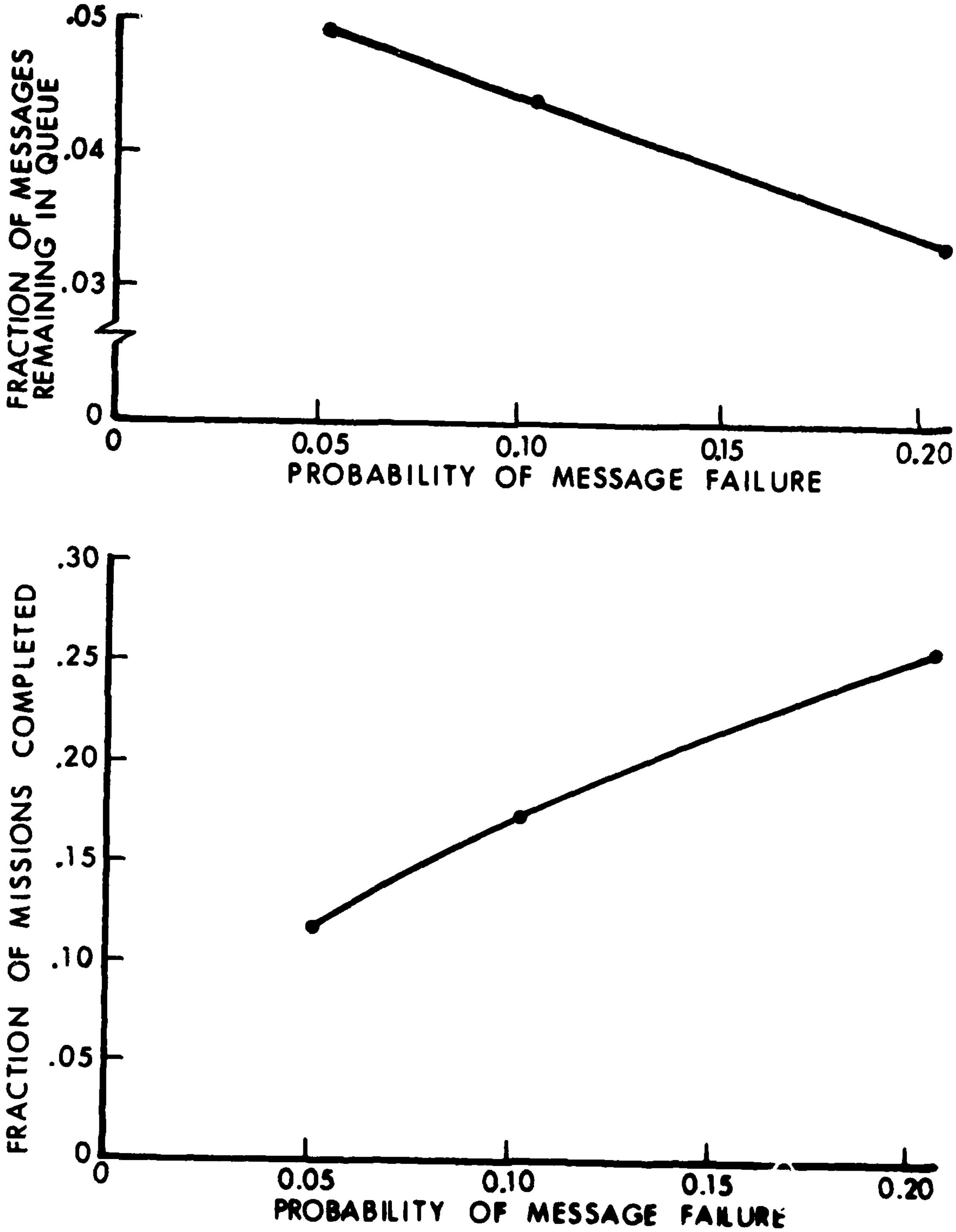


Figure 10. Effect of Message Failure

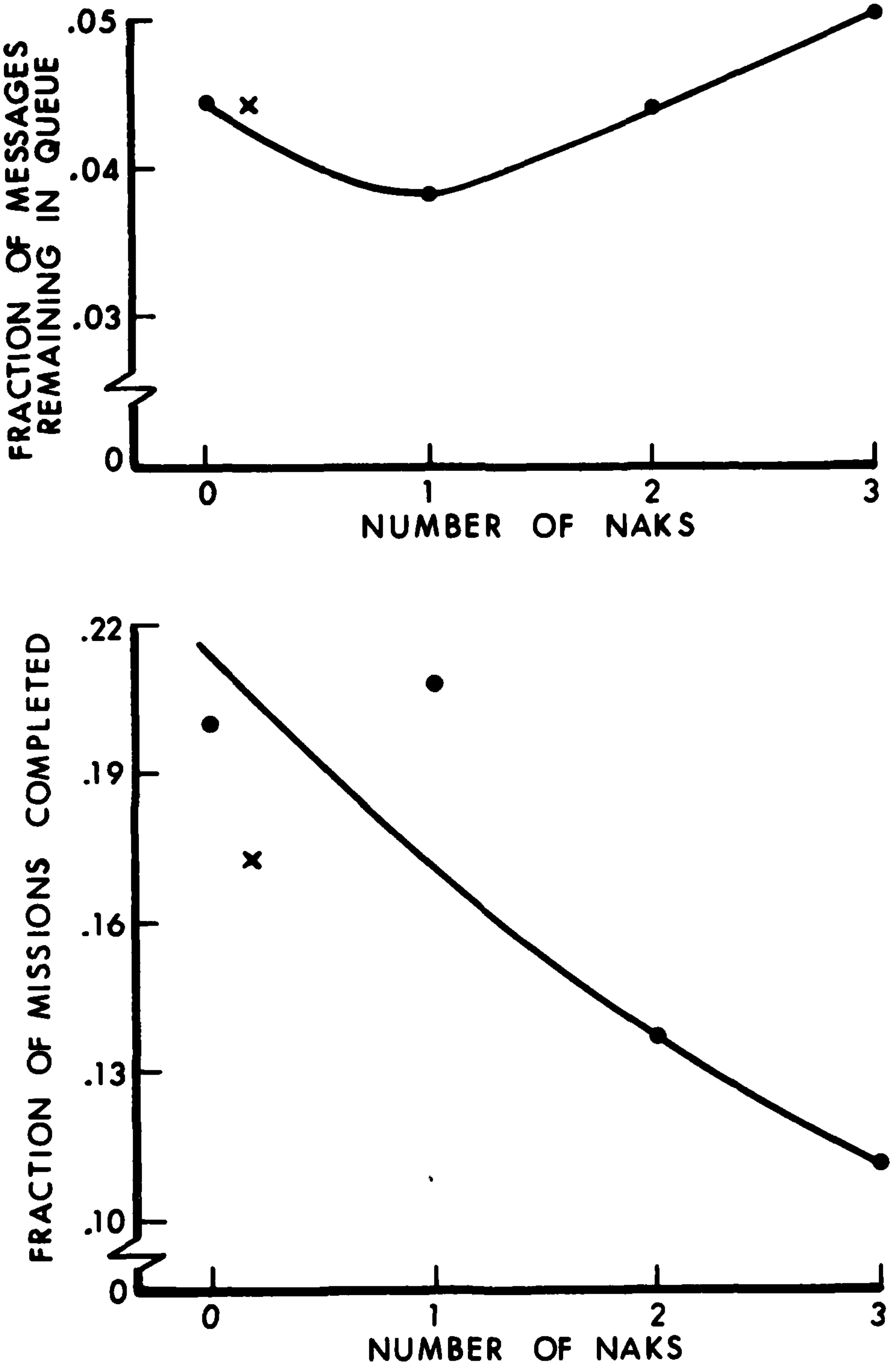


Figure 11. Effect of Message NAKs

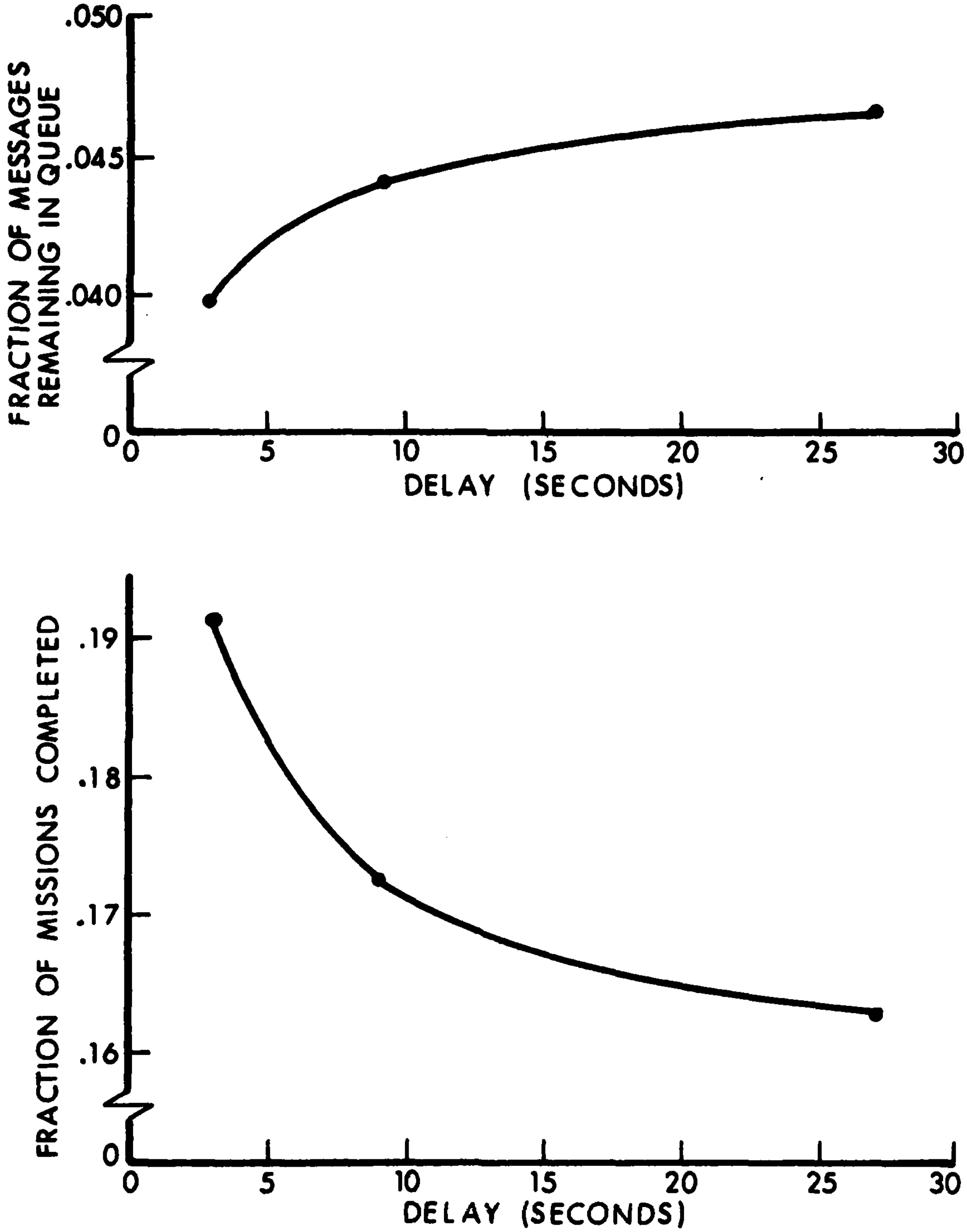


Figure 12. Effect of Computer Delay

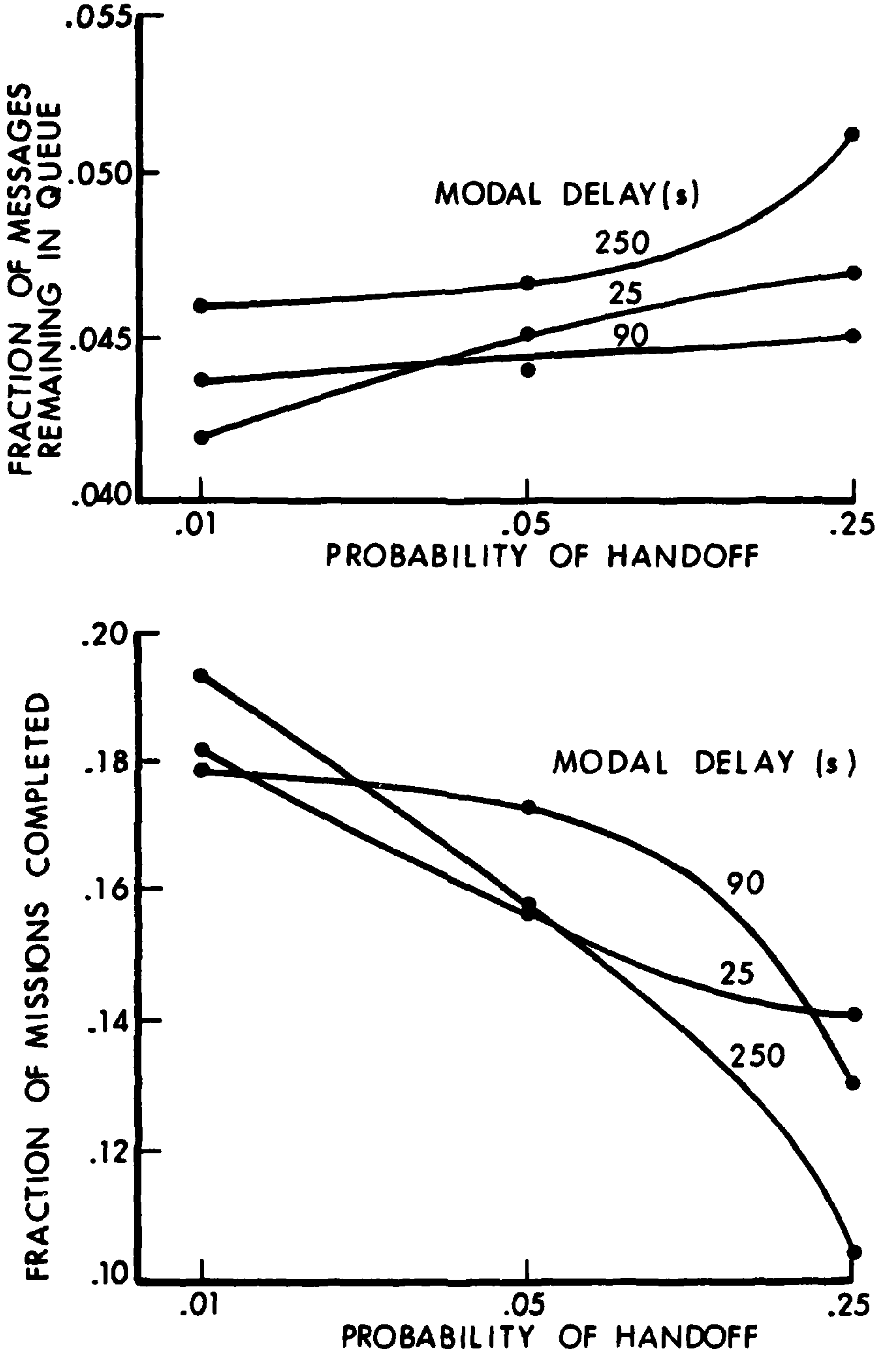


Figure 13. Effect of Handoff

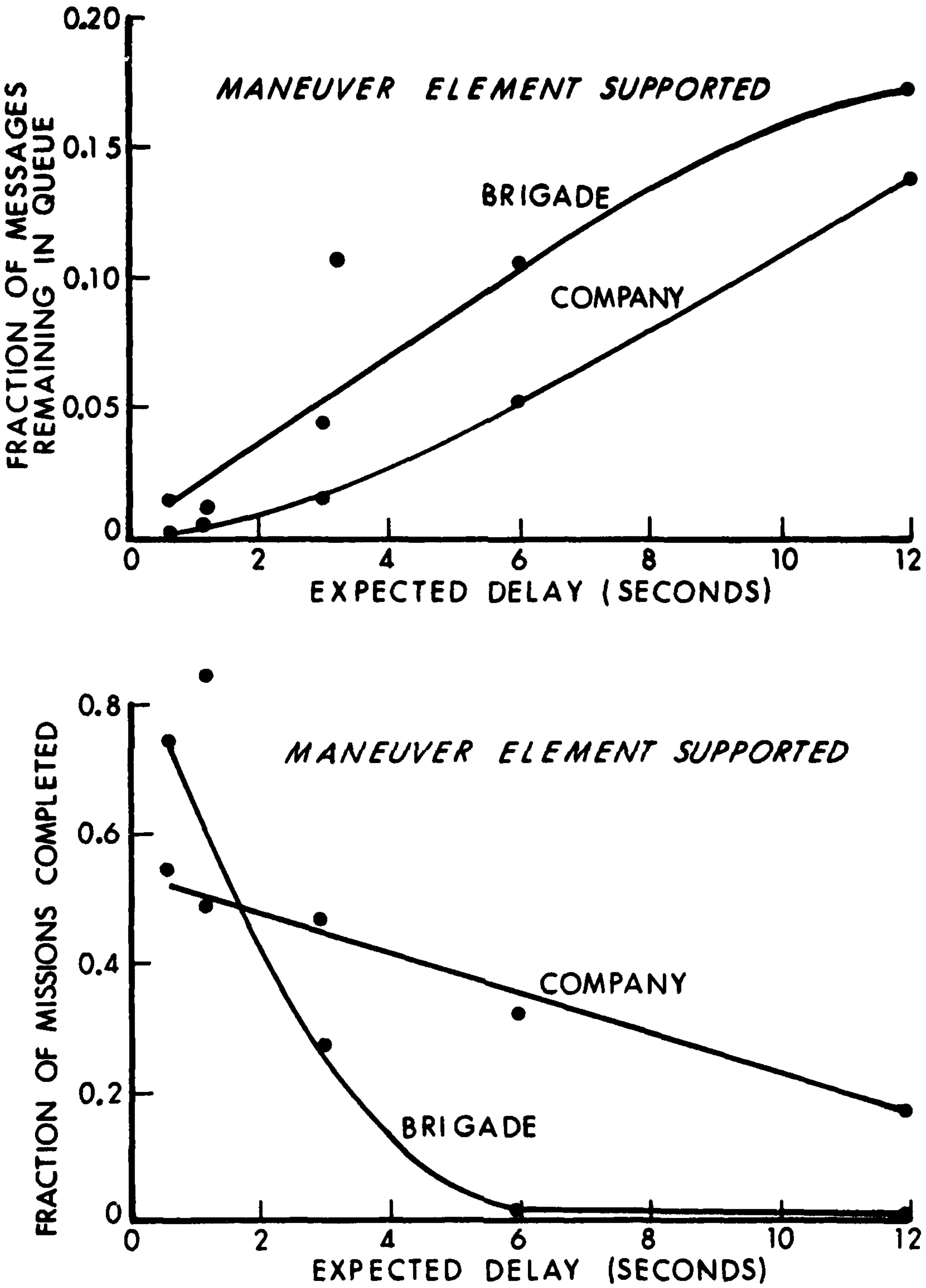


Figure 14. Effect of Net Access Delay

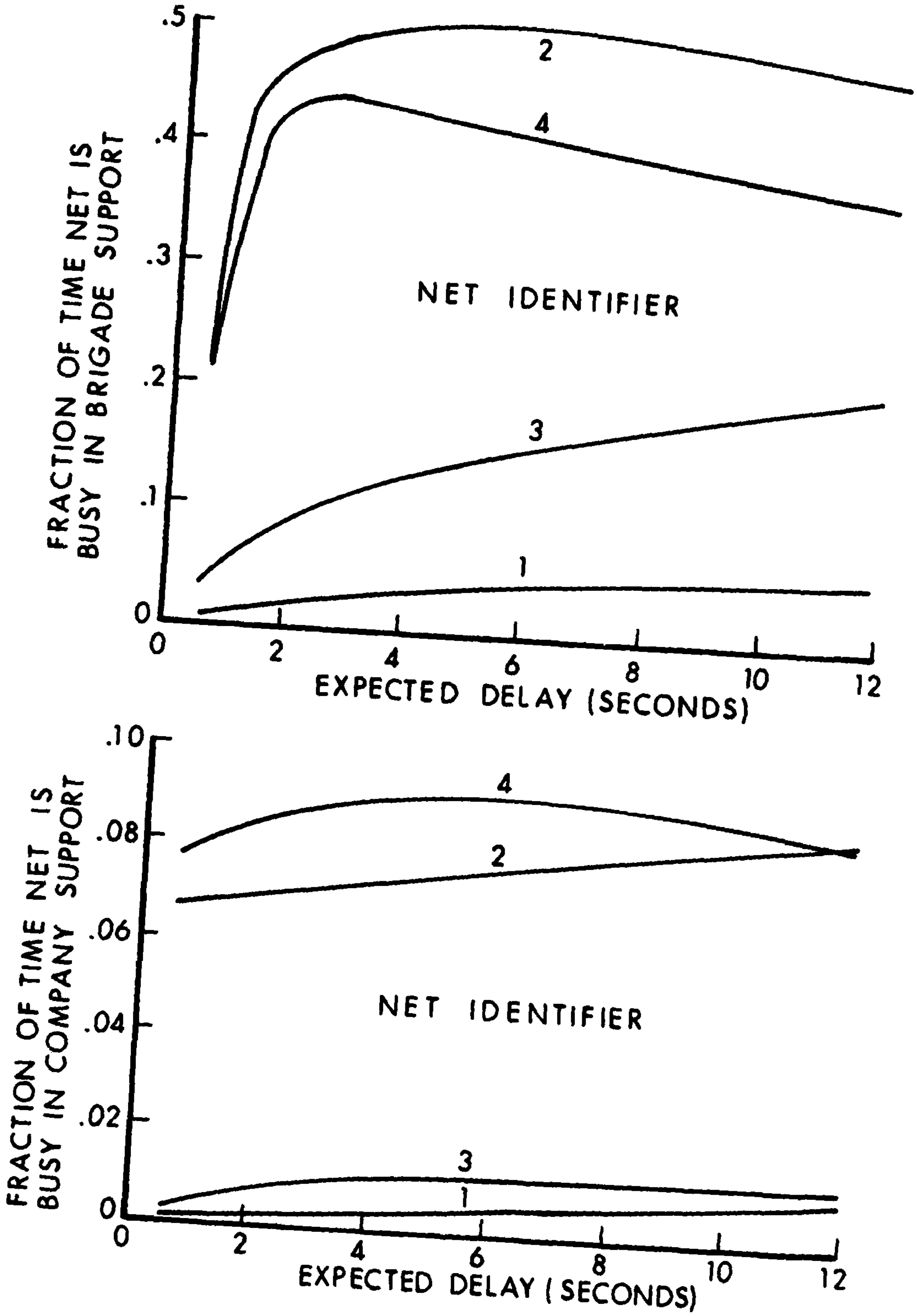


Figure 15. Net Usage as a Function of Net Access Delay

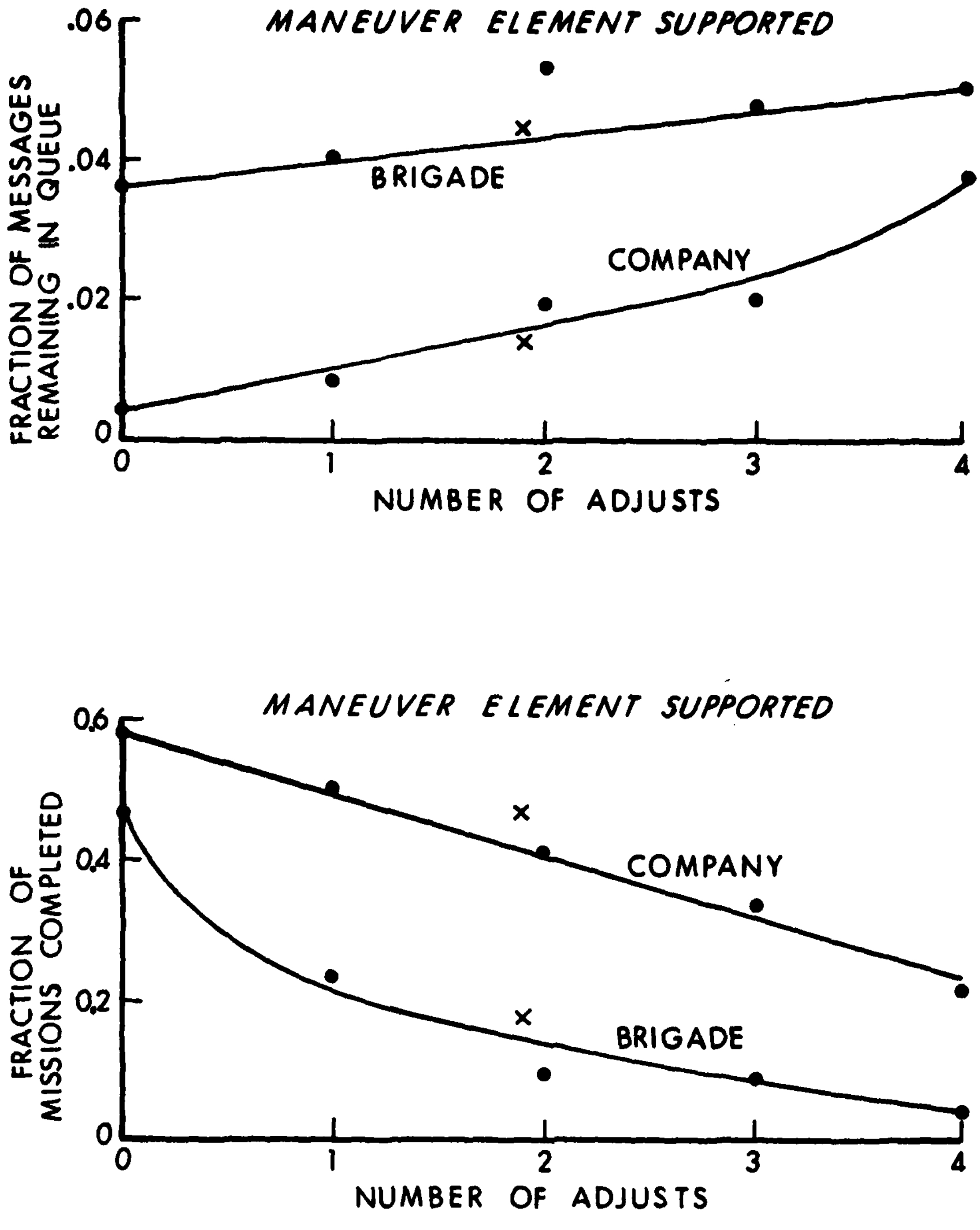


Figure 16. Effect of the Number of Adjusts

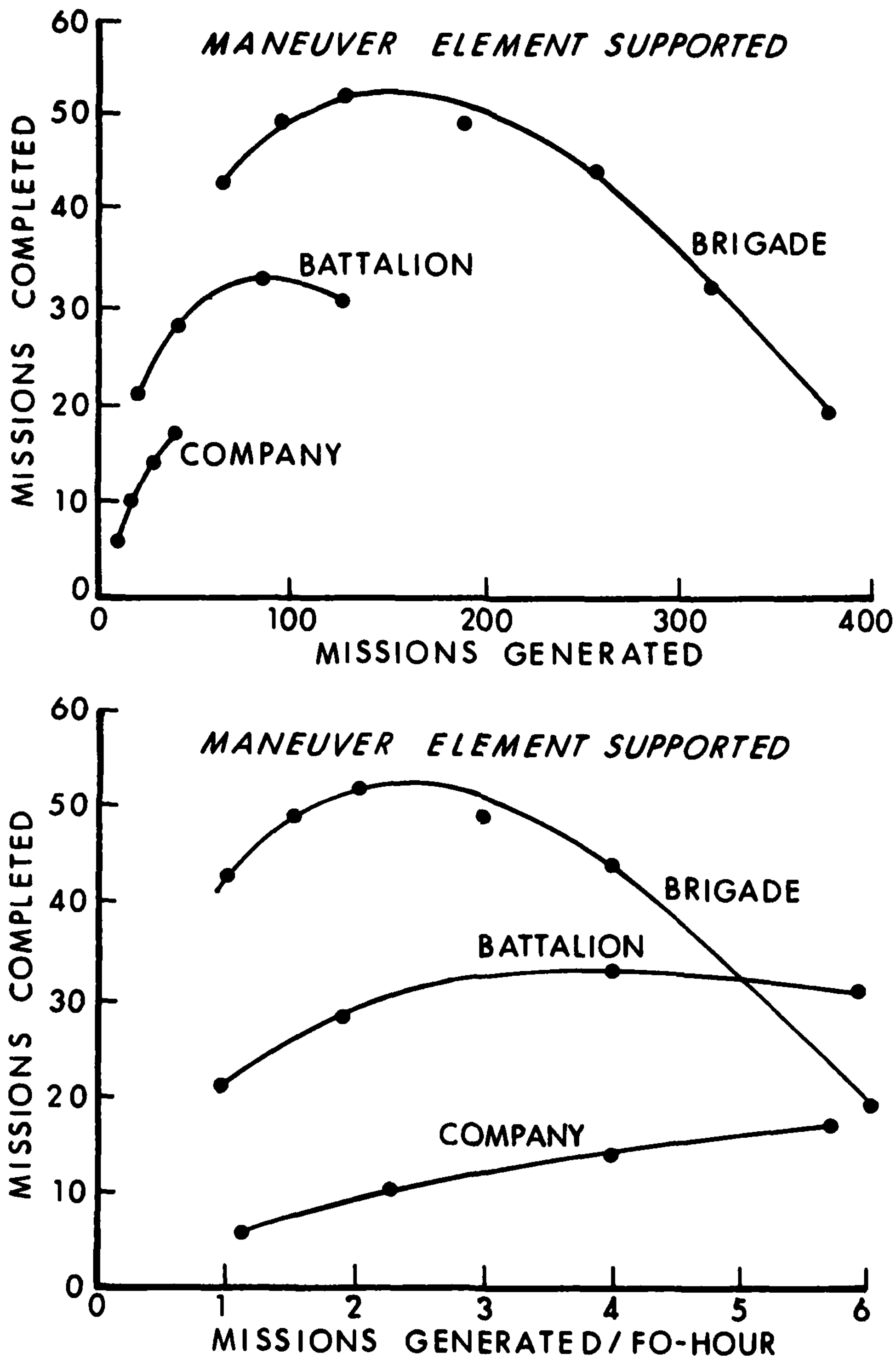


Figure 17. Effect of Mission Generation Rate

TABLE 1. SUMMARY OF HELBAT ACTIVITIES

HELBAT NO.	DATES	LOCATION	PRINCIPAL ISSUES
1	1969	Ft. Hood, TX	Target location accuracy, response time
2	Feb 1971	Ft. Hood, TX	FO performance using laser rangefinder
3	Apr 1972	Ft. Hood, TX	Using laser rangefinder to engage moving targets
4	Sep-Oct 1973	Ft. Sill, OK	Closed loop fire control
5	May 1975	Ft. Sill, OK	Howitzer mounted weapon error measurement systems systems
6	Oct 1976	Ft. Sill, OK	Hardware integration to support closed loop fire control
7	Feb-Mar 1979	Ft. Sill, OK	Increase battery automation; more closed loop fire control
8	Oct-Nov 1981	Ft. Sill, OK	Command, control, and communications (C^3) analysis

TABLE 2. CHARACTERISTICS OF THREE FIRE SUPPORT NETWORKS

Represented Factor	Fire Support Network Type		
	Brigade	Battalion	Company
Number of Units	50	18	10
Number of Links	70	24	12
Number of Nets	16	6	4
Number of Links to BNFDC (TACFIRE)	16	6	4
Number of Links in Type 1 Nets	27	9	3
Number of Links in Type 2 Nets	36	12	6
Number of Links in Type 3 Nets	1	1	1
Number of Links in Type 4 Nets	6	2	2
Number of FOs	27	9	3
Number of FISTs	9	3	1
Number of BNFSOs	3	1	1
Number of BNFDCs	1	1	1
Number of BDEFSOs	1	1	1
Number of Battery FDCs	3	1	1
Number of Gun Sections	6	2	2

TABLE 3. LENGTHS OF MESSAGES GENERATED IN MODEL

MESSAGE TYPE	MESSAGE LENGTH (BITS) MIN	MAX	MODE
1	372	492	432
2	5400	6600	5880
3	4200	5400	4800
4	2160	4260	3240
5	2160	5400	3780
6	720	2160	950

TABLE 4. LIST OF MODEL INPUT VARIABLE BASELINE VALUES

Number	Report Section	Variables	Baseline Values	
1	III.C.1.	Computer and Message Failure	P(Msg Failure)	= .103
			P(Comp Failure)	= .0004
			Delay - Min	= 6 seconds
			Max	= 30 "
			Mode	= 12 "
2	III.C.2.	NAK Sequence	P(0 NAK)	= 0.90
			P(1 NAK)	= 0.05
			P(2 NAK)	= 0.02
			P(3 NAK)	= 0.02
			P(4 NAK)	= 0.01
3	III.C.3	Human Delay	Delay - Min	= 0 seconds
			Max	= 60 "
			Mode	= 20 "
4	III.C.4.	Computer Delay for Fire Mission Processing	Delay	= 9 seconds
5	III.C.5	Delay for Non Fire Mission Processing	Delay - Min	= 0 seconds
			Max	= 9 "
			Mode	= 3 "
6	III.C.6.	Delay due to Relay Through FIST	Delay - Min	= 0 seconds
			Max	= 30 "
			Mode	= 6 "
7	III.C.7.	Waiting Time in Message Que	Time - Min	= 0 seconds
			Max	= 3 "
			Mode	= 2 "
8	III.C.8.	Delay in NAK Processing	Delay - Min	= 12 seconds
			Max	= 30 "
			Mode	= 15 "
9	III.C.9.	Handoff	Probability	= 0.05
			Delay - Min	= 10 seconds
			Max	= 120 "
			Mode	= 90 "
10	III.C.10	Preamble Times	Prob. = .02; Time	= 0 seconds
			.02	= .20 "
			.10	= .70 "
			.02	= 1.40 "
			.70	= 1.70 "
			.10	= 2.10 "
			.02	= 2.80
			.02	= 4.00

TABLE 4. LIST OF MODEL INPUT VARIABLE BASELINE VALUES (CONT'D)

Number	Report Section	Variables	Baseline Values
11	III.C.11.	Mission Stoppage	Probability = 0.05 Delay - Min = 120 seconds Max = 600 " Mode = 240 "
12	III.C.12.	Turn-On Time	Prob. = .30; Delay = .05 seconds .30 = .10 " .40 = .40 "
13	III.C.13.	Gun Setup Time	Time - Min = 0 seconds Max = 90 " Mode = 60 "
14	III.C.14.	NAK Sequence and Resulting Delay	P(4 NAKS) = 0.01 Delay = 1800 seconds
15	III.C.15.	Net Access Delay Time	Most Prob. Delay = 0.5 seconds Prob. of Delay = 0.90 " Number of Intervals = 0.90 " Spacing of Intervals = 0.5 "
16	III.C.16.	Adjust Fire Loop	P(0 Adjusts) = .05 P(1 Adjust) = .15 P(2 Adjusts) = .70 P(3 Adjusts) = .05 P(4 Adjusts) = .05

TABLE 5. Results of the Input Variable Analysis

INPUT ADDRESSED	CONDITIONS ADDRESSED					MESSAGES GENE-RATED	MESSAGES IN QUEUE	MISSIONS GENE-RATED	MISSIONS COMP-LETED	FRACTION OF TIME INDICATED NET IS BUSY 1	2	3	4	FRACTION OF TIME RELAYS ARE BUSY
COMPUTER AND MESSAGE FAILURE	P(FAILURE) COMP.	P(FAILURE) MSG.	DELAYS MIN.	DELAYS MAX.	DELAYS MODE									
	.0004	.103	2	10	4	8129	364	260	45	.0298	.4366	.0981	.3981	.1296
	.0004	.103	6	30	12	8568	376	255	44	.0211	.4601	.1095	.4369	.1225
	.0004	.103	18	90	36	8536	468	289	29	.0275	.5029	.1061	.4055	.1267
	.0002	.103	6	30	12	8056	421	279	25	.0287	.4337	.1197	.4318	.1282
	.0008	.103	6	30	12	8922	518	311	32	.0242	.5039	.1214	.4147	.1212
	.0004	.052	6	30	12	8700	428	266	31	.0223	.5019	.1190	.4075	.1204
	.0004	.206	6	30	12	8894	299	222	57	.0224	.4428	.0919	.4932	.1319
NAK SEQUENCE	NUMBER OF NAKS													
	0					8404	373	241	48	.0246	.4724	.1065	.4447	.1281
	1					8498	323	225	49	.0216	.4150	.0858	.4041	.1408
	2					8788	385	257	35	.0225	.4795	.1026	.3916	.1320
	3					8652	435	289	32	.0283	.4356	.1162	.4254	.1337
	4					252	252	252	0	.0708	.1720	0.0000	0.0000	0.0000
HUMAN DELAY	DELAY MIN.	DELAY MAX.	DELAY MODE											
	0	30	10			8632	410	275	38	.0190	.4362	.1107	.4511	.1237
	0	60	20			8568	376	255	44	.0211	.4601	.1095	.4369	.1225
	0	120	40			8683	391	267	38	.0207	.4816	.1166	.4567	.1243
COMPUTER DELAY FOR FIRE MISSION PROCESSING	DELAY													
	3					8853	351	240	46	.0226	.4968	.0956	.4908	.1359
	9					8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	27					8675	404	270	44	.0243	.4984	.1158	.4867	.1365

TABLE 5. Results of the Input Variable Analysis (Cont'd)

INPUT ADDRESSED	CONDITIONS ADDRESSED			MESSAGES GENE-RATED	MESSAGES IN QUEUE	MISSIONS GENE-RATED	MISSIONS COMP-LETED	FRACTION OF TIME INDICATED NET IS BUSY 1	2	3	4	FRACTION OF TIME RELAYS ARE BUSY
NON-FIRE MISSION PROCESSING DELAY	DELAY MIN.	MAX.	MODE									
	0	3	1	8473	411	271	39	.0218	.4687	.1149	.3981	.1227
	0	9	3	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	0	27	9	8884	409	263	32	.0201	.4708	.1055	.4972	.1333
DELAY DUE TO RELAY THROUGH FIST	DELAY MIN.	MAX.	MODE									
	0	10	2	9079	455	271	29	.0251	.4679	.1159	.4810	.1237
	0	30	6	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	0	90	18	7939	469	271	28	.0233	.4487	.1245	.3765	.1262
WAITING TIME IN MESSAGE QUEUE	TIME MIN.	MAX.	MODE									
	0	2	1	8351	418	268	17	.0278	.4704	.0916	.3599	.1225
	0	3	2	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	0	6	4	8493	417	272	25	.0234	.4288	.1115	.4168	.1380
DELAY IN NAK PROCESSING	DELAY MIN.	MAX.	MODE									
	6	15	8	6662	358	235	48	.0242	.4450	.1161	.4576	.1186
	12	30	15	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	24	60	30	6407	357	241	45	.0244	.4125	.0871	.4694	.1379

TABLE 5. Results of the Input Variable Analysis (Cont'd)

INPUT ADDRESSED	CONDITIONS ADDRESSED				MESSAGES GENE- RATED	MESSAGES IN QUEUE	MISSIONS GENE- RATED	MISSIONS COMP- LETED	FRACTION OF TIME INDICATED NET IS BUSY 1	2	3	4	FRACTION OF TIME RELAYS ARE BUSY
HANDOFF	DELAY												
	PROB.	MIN.	MAX.	MODE									
	.01	3	40	25	6586	361	243	44	.0193	.4204	.1039	.4346	.1180
	.05	3	40	25	6565	386	256	40	.0261	.4913	.1261	.4137	.1208
	.25	3	40	25	6299	390	256	36	.0166	.4498	.1205	.4632	.1298
	.01	10	120	90	6476	371	246	44	.0227	.4985	.1021	.4317	.1293
	.05	10	120	90	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	.25	10	120	90	6766	395	269	35	.0214	.4481	.1301	.4349	.1177
	.01	30	400	250	6495	392	243	47	.0200	.4410	.1069	.4704	.1259
	.05	30	400	250	6541	398	268	42	.0232	.4893	.1235	.4235	.1139
	.25	30	400	250	6511	436	280	29	.0203	.4476	.1181	.4188	.1295
PREAMBLE TIME	BASELINE VALUES HALVED				9235	403	286	39	.0285	.5050	.1204	.4259	.1166
	BASELINE VALUES				6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	BASELINE VALUES DOUBLED				6206	439	284	37	.0208	.4946	.1276	.4493	.1235
MISSION STOPPAGE	DELAY												
	PROB.	MIN.	MAX.	MODE									
	.02	60	300	120	6543	401	259	38	.0198	.4172	.1033	.4709	.1359
	.05	60	300	120	6426	452	285	21	.0216	.4425	.1106	.4098	.1342
	.10	60	300	120	6624	389	260	41	.0224	.4469	.1079	.4268	.1285
	.02	120	600	240	6586	445	279	36	.0234	.4636	.1050	.4016	.1308
	.05	120	600	240	6568	378	255	44	.0211	.4601	.1095	.4369	.1225
	.10	120	600	240	6706	460	290	26	.0258	.4230	.1035	.3773	.1327
	.02	240	1200	480	6333	405	260	38	.0228	.4345	.1307	.4601	.1375
	.05	240	1200	480	6246	381	243	38	.0218	.4468	.0982	.4358	.1324
	.10	240	1200	480	7952	366	251	46	.0277	.4345	.0861	.3798	.1189

TABLE 5. Results of the Input Variable Analysis (Cont'd)

INPUT ADDRESSED	CONDITIONS ADDRESSED			MESSAGES GENE-RATED	MESSAGES IN QUEUE	MISSIONS GENE-RATED	MISSIONS COMP-LETED	FRACTION OF TIME INDICATED NET IS BUSY 1	2	3	4	FRACTION OF TIME RELAYS ARE BUSY
TURN-ON TIME	DELAY WITH GIVEN PROB. .03	.03	.04									
	.01	.02	.06	8969	440	270	36	.0221	.4755	.1265	.4736	.1214
	.05	.10	.40	8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	.25	.50	2.0	8287	470	282	29	.0233	.4827	.1127	.4324	.1362
GUN SETUP TIME	TIME MIN.	MAX.	MODE									
	0	3	2	8852	447	267	31	.0180	.4423	.1090	.4214	.1394
	0	90	60	8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	0	300	200	8533	397	270	41	.0276	.4408	.1069	.4656	.1147
NAR SEQUENCE AND RESULTING DELAY	P(4 NARS)	DELAY										
	0	1800		8315	375	242	50	.0240	.4614	.1084	.4474	.1246
	.01	900		8448	393	252	43	.0209	.4790	.0985	.4511	.1137
	.01	1800		8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	.01	3600		8640	446	273	45	.0179	.4361	.1285	.4028	.1257
	.01	7200		8671	399	283	32	.0213	.5036	.1104	.3692	.1302
	.03	225		8557	402	258	53	.0310	.4594	.0890	.4073	.1263
	.03	450		8774	366	255	37	.0276	.4886	.0948	.3989	.1355
	.03	900		8471	509	292	16	.0214	.4621	.1248	.3863	.1257
	.03	1800		8425	452	279	26	.0241	.4727	.1243	.5283	.1249
	.03	3600		8210	349	258	32	.0236	.4216	.1036	.5266	.1304
	.10	112		7945	464	269	39	.0282	.4449	.1094	.4124	.1272
	.10	225		7863	375	246	34	.0257	.4623	.1079	.4545	.1134
	.10	450		7555	376	254	39	.0246	.4501	.1305	.4157	.1204
	.10	900		7848	409	254	26	.0242	.4791	.1076	.4166	.1276
	.10	1800		7701	435	257	25	.0255	.4263	.1007	.3842	.1243
	1.0	1800		252	252	252	0	.0708	.1720	0.0000	.0000	0.0000

TABLE 5. Results of the Input Variable Analysis (Cont'd)

INPUT ADDRESSED	CONDITIONS ADDRESSED			MESSAGES GENE-RATED	MESSAGES IN QUEUE	MISSIONS GENE-RATED	MISSIONS COMP-LETED	FRACTION OF TIME INDICATED NET IS BUSY 1	2	3	4	FRACTION OF TIME RELAYS ARE BUSY
NET ACCESS DELAY TIME	PROB.=.9 VALUE	STEP	EXPECTED DELAY									
(BRIGADE SUPPORT)	.1	.1	.595	15361	217	267	198	.0082	.2301	.0275	.2547	.1423
	.2	.2	1.190	15911	178	274	232	.0131	.4027	.0558	.3913	.1333
	.5	.5	2.975	8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	1.0	1.0	5.950	4906	518	261	3	.0388	.5035	.1797	.4146	.1405
	2.0	2.0	11.900	2790	461	264	3	.0557	.4530	.1959	.3517	.0959
(COMPANY SUPPORT)	.1	.1	.595	3925	9	31	17	.0009	.0653	.0029	.0838	.0237
	.2	.2	1.190	2423	11	29	14	.0019	.0731	.0059	.0794	.0270
	.5	.5	2.975	1516	22	30	14	.0026	.0706	.0065	.0842	.0250
	1.0	1.0	5.950	1348	71	31	10	.0057	.0681	.0094	.0893	.0230
	2.0	2.0	11.900	1068	148	29	5	.0112	.0710	.0135	.0909	.0241
ADJUST FIRE LOOP	NUMBER OF ADJUSTS		EXPECTED MSGS/MSN									
(BRIGADE SUPPORT)	0		32.28	8226	303	258	121	.0238	.4389	.1083	.4422	.1266
	1		44.86	8691	351	250	58	.0240	.4363	.1122	.3953	.1174
	BASELINE		56.18	8568	378	255	44	.0211	.4601	.1095	.4369	.1225
	2		57.44	8373	444	277	25	.0244	.4750	.1115	.3804	.1237
	3		70.02	8839	420	271	23	.0239	.4663	.1055	.4661	.1291
	4		82.60	8873	443	258	11	.0240	.4443	.1370	.4314	.1174
(COMPANY SUPPORT)	0		32.28	1462	7	29	17	.0027	.0720	.0089	.0799	.0235
	1		44.86	1494	13	28	14	.0023	.0671	.0086	.0912	.0230
	BASELINE		56.18	1516	22	30	14	.0026	.0706	.0065	.0842	.0250
	2		57.44	1503	29	27	11	.0019	.0689	.0093	.0823	.0225
	3		70.02	1576	31	36	12	.0028	.0763	.0083	.0800	.0273
	4		82.60	1592	59	42	9	.0034	.0628	.0052	.0773	.0332

TABLE 6. NET USAGE DEFINITIONS

NET NUMBER	UNITS CONTAINED IN NET
1	FO, FIST
2	FIST, BNFSO, BNFDC, BTRY FDC
3	BNFDC, BDEFSO
4	BTRY FDC, GUN SECTIONS

TABLE 7. NAK NUMBERS AND PROBABILITIES INVESTIGATED

P(4 NAK)	P(0 NAK)	P(1 NAK)	P(2 NAK)	P(3 NAK)
0.00	0.91	0.05	0.02	0.02
0.01	0.90	0.05	0.02	0.02
0.03	0.88	0.05	0.02	0.02
0.10	0.83	0.04	0.02	0.01
1.00	0.00	0.00	0.00	0.00

TABLE 8. CONDITIONS FOR MISSION PROFILE ANALYSIS

MISSION PROFILE	TACTICAL FIRE CONTROL PERFORMED AT	MESSAGES/MISSION		
		MIN	MEAN	MAX
BASELINE	BATTALION	57.9	68.8	120.3
TACFIRE BASELINE A	FIST	58.0	70.6	128.0
TACFIRE BASELINE B	BATTALION	60.0	72.6	130.0
TACFIRE SMART A	FIST	67.7	74.9	107.7
TACFIRE SMART B	BATTALION	76.9	84.1	116.9
TACFIRE SMART C	BRIGADE	69.7	76.9	109.7

TABLE 9. RESULTS OF MISSION PROFILE ANALYSIS

MISSION PROFILE	MESSAGES			MISSIONS			FRACTION OF TIME INDICATED NET IS BUSY			
	GEN.	COMP.	FRAC. COMP.	GEN.	COMP.	FRAC. COMP.	1	2	3	4
BASELINE	8568	8190	0.956	255	44	0.172	.0211	.4601	.1095	.4369
TACFIRE BASELINE A	7521	7151	0.951	279	29	0.104	.0195	.4802	.2252	.3957
TACFIRE BASELINE B	8104	7700	0.950	274	28	0.102	.0223	.4844	.2087	.3879
TACFIRE SMART A	7408	7030	0.949	266	30	0.113	.0324	.4737	.4505	.2633
TACFIRE SMART B	6927	6426	0.928	268	15	0.056	.0541	.4798	.4925	.2240
TACFIRE SMART C	3877	3595	0.904	262	10	0.038	.0525	.2496	.4960	.1010

TABLE 10. COMPARISON OF BRL AND AMSAA TACFIRE COMMUNICATIONS SIMULATIONS

MSNS/HR	FRACTION OF FIRE MISSIONS COMPLETED			TIME TO CONDUCT FIRE MISSIONS - MINUTES									MAXIMUM NUMBER OF MISSIONS IN QUEUE		
				MINIMUM			MEAN			MAXIMUM					
GEN	AMSAA	BRL 1	BRL 4	AMSAA	BRL 1	BRL 4	AMSAA	BRL 1	BRL 4	AMSAA	BRL 1	BRL 4	AMSAA	BRL 1	BRL 4
15	0.92	0.48	0.97	7.86	9.38	7.65	8.15	16.91	17.96	11.60	27.90	30.30	1.13	11	2
30	0.88	0.70	0.92	7.86	12.60	12.25	8.70	18.91	24.36	15.30	26.25	58.67	3.46	9	9
45	0.86	0.42	0.55	7.86	14.11	14.11	9.88	22.94	36.54	21.10	31.62	86.51	6.27	28	86
60	0.79	0.29	0.37	7.86	17.04	17.04	12.50	27.16	54.30	28.13	37.04	120.40	12.43	54	152
75	0.66	0.11	0.24	7.86	20.72	20.72	16.02	32.69	59.39	38.95	44.40	162.34	25.71	72	232
							BASELINE								
24	-	0.36	0.69	-	22.60	22.60	-	38.42	66.21	-	44.98	124.11	-	9	24
63	-	0.03	0.10	-	45.77	45.77	-	46.64	45.77	-	46.64	105.73	-	62	214

NOTES: "BRL 1" designates the BRLMPM simulating one hour of battle time using AMSAA input values. "BRL 4" designates the BRLMPM simulating four hours of battle time using AMSAA input values. "AMSAA" designates the AMSAA model simulating one hour of battle time. "Baseline" designates baseline runs made with the BRLMPM using BRL input values.

TABLE 11. SUMMARY OF INPUT VARIABLE SENSITIVITIES

INPUT VARIABLE	SENSITIVITY
Delay due to Excessive Number of NAKs	Great
Net Access Delay Time	Great
Adjust Fire Loop	Great
Message Failure	Moderate
Number of NAKs	Moderate
Computer Delay (Fire Mission Processing)	Moderate
Handoff	Moderate
Human Delay	Small or None
Computer Delay (Non-Fire Mission Processing)	Small or None
Relay Delay	Small or None
Waiting Time in Message Queue	Small or None
Delay in NAK Processing	Small or None
Preamble Time	Small or None
Mission Stoppage	Small or None
Turn-On Time	Small or None
Gun Set-Up Time	Small or None

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